Forecasting the "Hard Rain"

NASA's Planetary Defense Efforts

https://www.nasa.gov/planetarydefense/overview

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March 15, 2018

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“Shooting Stars” - Meteors

- Average size = sand grain
- Bright one = rice grain
- But traveling about 20 km per second, or 40,000 miles per hour!
- “The Hard Rain”

In space:

< 1 meter = meteoroid

> 1 meter = asteroid

Meteor: in atmosphere

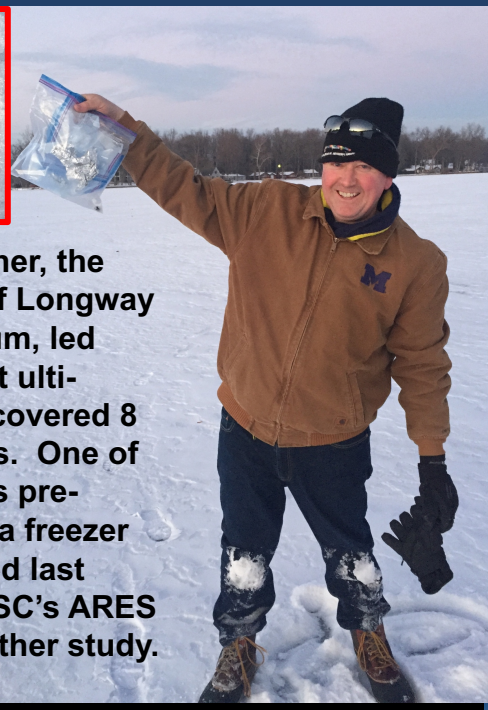
Meteorite: on ground

Michigan Bolide and Meteorites

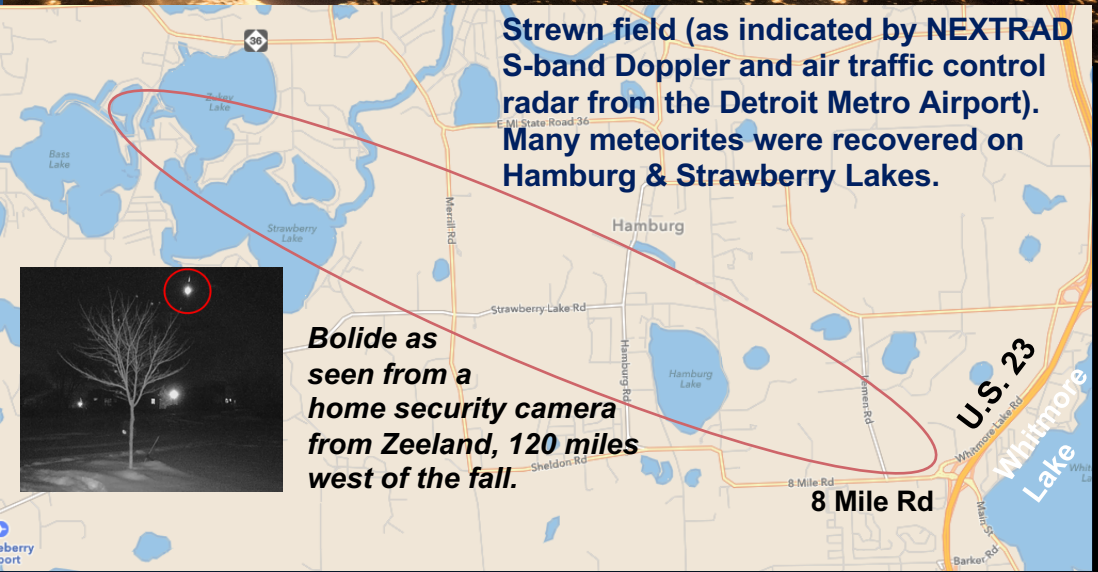
The incoming trajectory was 21 degrees from zenith.

21°

On 16 January 2018 at 08:08:28 PM EST, the skies over southern Michigan were set ablaze when a meteoroid approximately 2 meters in size ripped through the atmosphere.



Todd Slisher, the director of Longway Planetarium, led teams that ultimately recovered 8 meteorites. One of which was preserved in a freezer and arrived last week at JSC's ARES lab for further study.

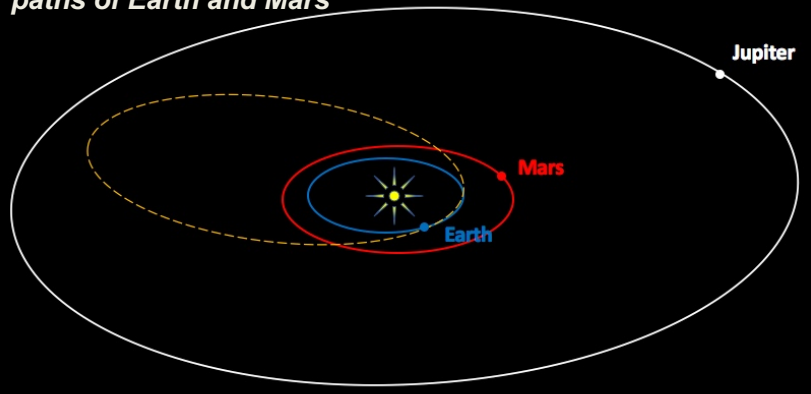


Strewn field (as indicated by NEXTRAD S-band Doppler and air traffic control radar from the Detroit Metro Airport). Many meteorites were recovered on Hamburg & Strawberry Lakes.

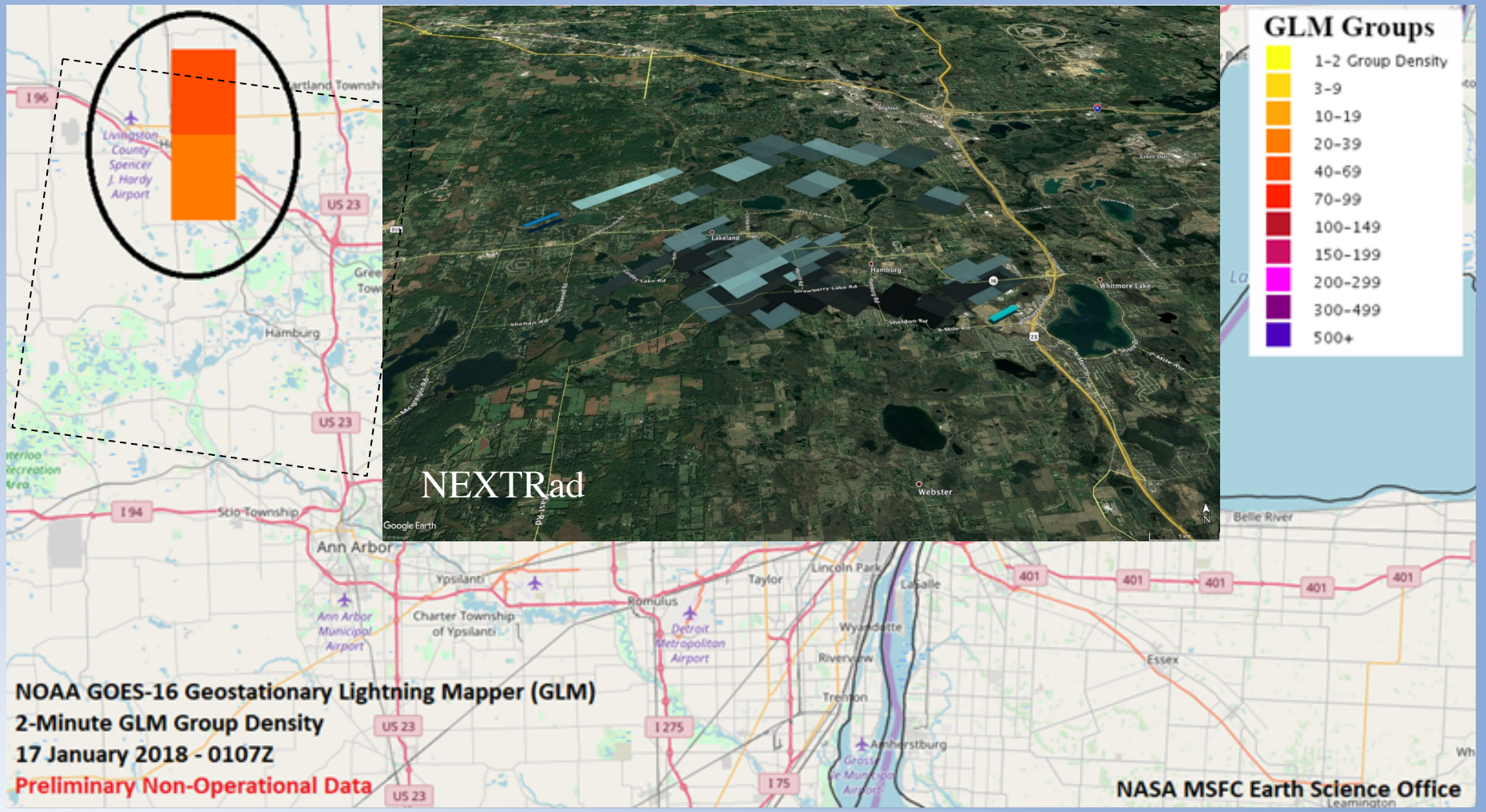
Bolide as seen from a home security camera from Zeeland, 120 miles west of the fall.

8 Mile Rd

Based on the local final trajectory to the Earth, an approximate orbit indicates the meteoroid's final orbit crossed the paths of Earth and Mars



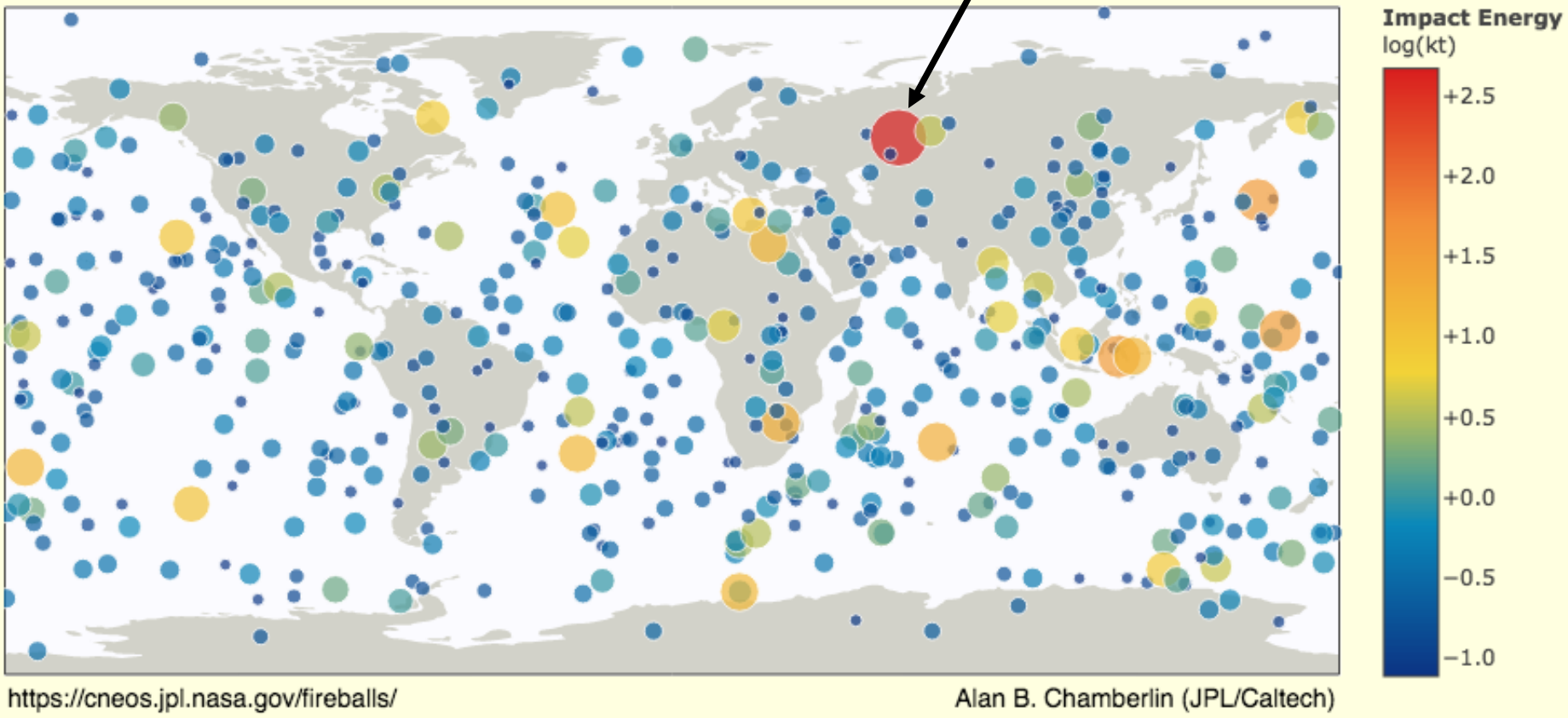
Meteors: as seen on Wx Sensors



Fireballs Reported by US Government Sensors

(1988-Apr-15 to 2018-Feb-01)

Chelyabinsk impact 2013



https://cneos.jpl.nasa.gov/fireballs/

Alan B. Chamberlin (JPL/Caltech)

Chelyabinsk Impact February 15, 2013 – Dashcam and surveillance camera compilation

Chelyabinsk Event – 15 February 2013

- Natural object entering Earth's atmosphere
  - Large meteoroids = small asteroids
  - Interested in any larger than 1 meter in size
- Entry velocity much higher than re-entering space debris
- Characteristic ionization trail and detonation
- Chelyabinsk Event largest and most documented in recent decades
  - 17-19 meters in size, energy release equal to approximately 440 kilotons TNT at 23 km altitude

February 15, 2013
1613 citizens injured
~$30 million damages

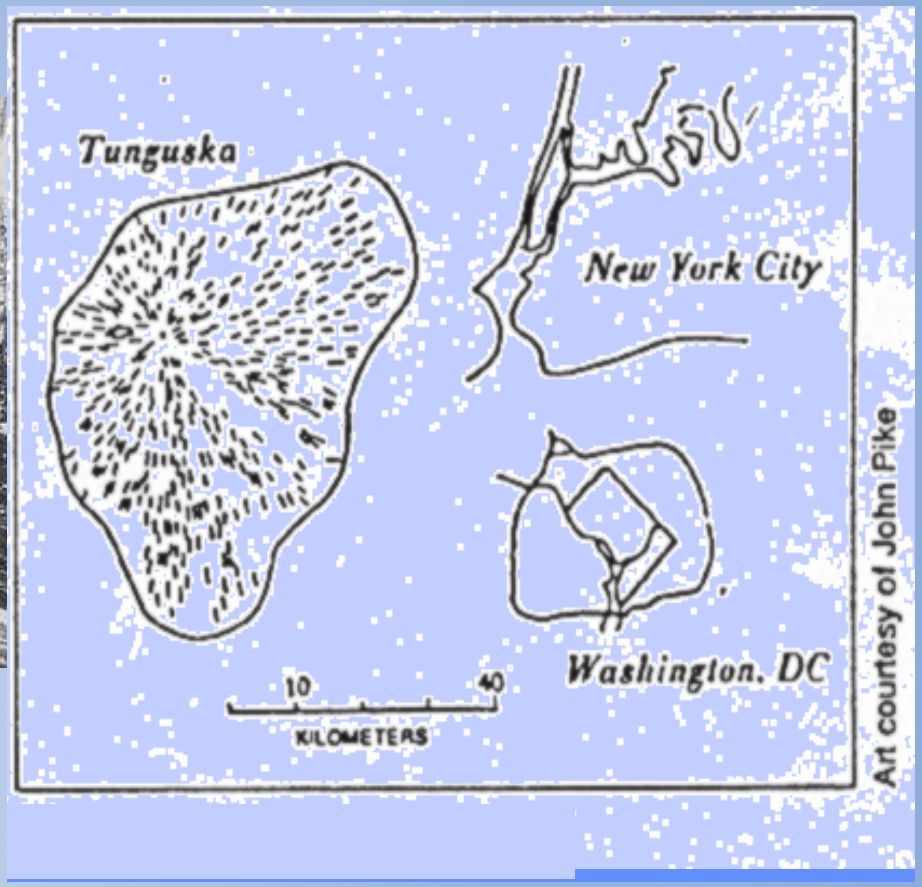
Watch https://www.youtube.com/watch?v=dpmXyJrs7iU#t=27.4032078

EFFECTS: TUNGUSKA EVENT – June 30 1908

On June 30, 1908 an object estimated to be 40 meters in size entered Earth's atmosphere over the Tunguska River in remote Siberia

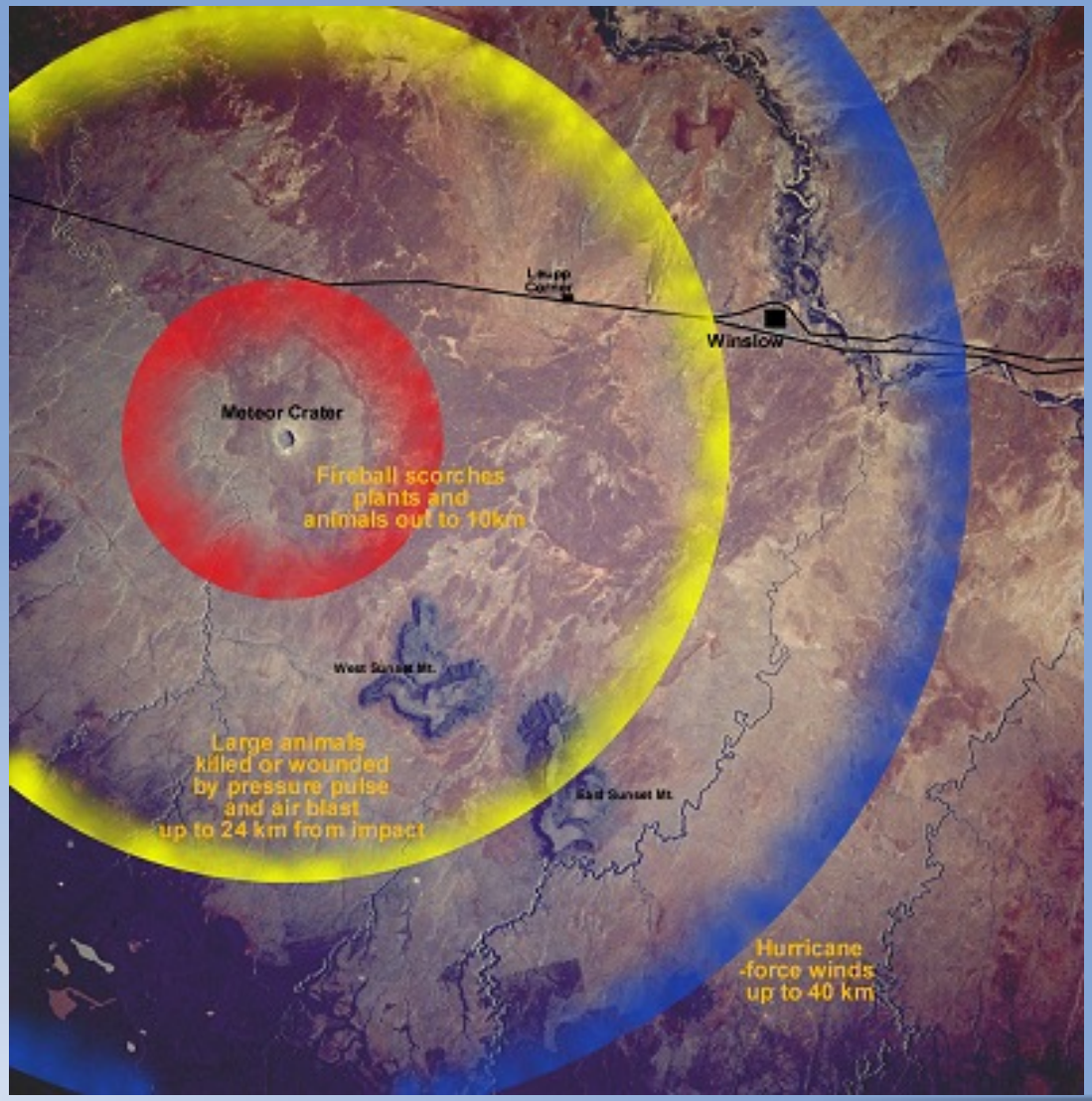
When scientists arrived almost 20 years later they found about 800 square miles of fallen trees

RELATIVE AREA OF DEVASTATION



Why This is Important

Why This is Important



Barringer Crater
Winslow, Arizona

Diameter – ~ 1 mile
Age – 50,000 yrs

Impactor size - ~50m
Energy released = ~5Mt

National Interest in Asteroid Hazard

Congressman Lamar Smith (R-Texas) — Chairman of U.S. House of Representatives Committee on Science, Space, and Technology

"Threats from Space: A Review of U.S. Government Efforts to Track and Mitigate Asteroids and Meteors, Part 1"

Congressional Hearing by the U.S. House of Representatives Committee on Science, Space, and Technology (19 March 2013), post-Chelyabinsk event

General William Shelton — then-Chief of the U.S. Air Force Space Command

"The Administration places a high priority on tracking asteroids and protecting our planet from them, as evidenced by the five-fold increase in the budget for NASA's NEOO program since 2009. The United States has an effective program for discovering larger NEOs, but we need to improve our capabilities for the identification and characterization of smaller NEOs."

John Holdren, Director, Office of Science and Technology Policy, Science advisor to President Barack Obama

National Space Policy, June 28 2010 – "Pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet and to identify potentially resource-rich planetary objects." https://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

Administration guidance was provided in OSTP Letter to Congress dated 15 October, 2010, as Response to Section 804 of NASA Authorization Act of 2008
https://www.whitehouse.gov/sites/default/files/microsites/ostp/ostp-letter-neo-senate.pdf

Planetary Defense Coordination Office

This new office was established in January 2016 at NASA HQ to coordinate planetary defense related activities across NASA, and coordinate both US interagency and international efforts and projects to address and plan response to the asteroid impact hazard.

Mission Statement:

Lead national and international efforts to:

- Detect any potential for significant impact of planet Earth by natural objects
- Appraise the range of potential effects by any possible impact
- Develop strategies to mitigate impact effects on human welfare

We must Find Them First!

Discover & Characterize

Near-Earth Object Observations Program

Kelly Fast
NEOO Program Manager
Planetary Defense Coordination Office
NASA HQ
March 15, 2018

Terminology

- "Near Earth Objects (NEOs)"- any small body (comet or asteroid) passing within 1.3 astronomical unit (au) of the Sun
  - 1 au is the distance from Earth to Sun = ~ 93 million miles
  - NEOs are predicted to pass within ~ 30 million miles of Earth's orbit
  - e.g. any small body passing between orbits of Venus to Mars
  - Population of:
    - Near Earth Asteroids (NEAs)
    - Near Earth Comets (NECs) – also called Earth Approaching Comets (EACs)
      - 106 currently known
- "Potentially Hazardous Objects (PHOs)" – small body that has potential risk of impacting the Earth at some point in the future
  - NEOs passing within 0.05 au of Earth's orbit
    - ~ 5 million miles = 20 times the distance to the Moon
  - Appears to be almost 20% of all NEOs discovered

NEO Observations Program

Detection and tracking of natural objects – asteroids and comets – that approach within 28 million miles of Earth's orbit

US component to International Asteroid Warning Network

Has provided 98% of new detections of NEOs since 1998

Began with NASA commitment to House Committee on Science in May 1998 to find at least 90% of 1 km and larger NEOs

- That goal reached by end of 2010

NASA Authorization Act of 2005 increased scope of objectives:

- Amended National Aeronautics and Space Act of 1958 ("NASA Charter") to add:

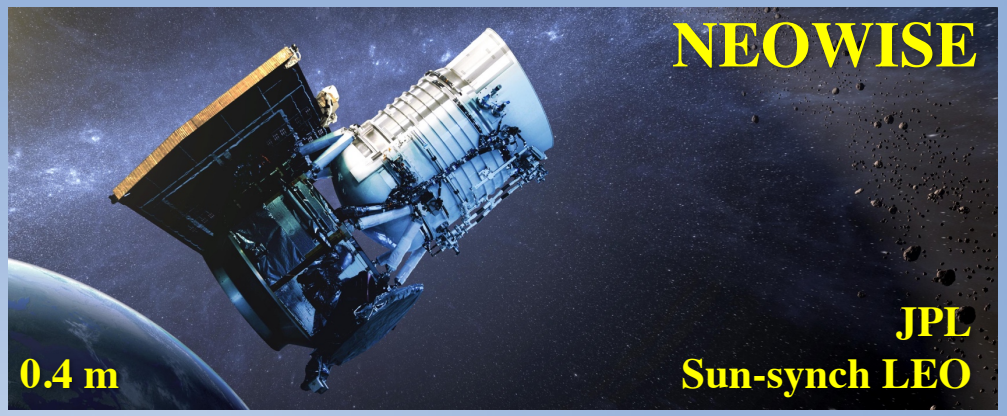
  ''The Congress declares that the general welfare and security of the United States require that the unique competence of the National Aeronautics and Space Administration be directed to detecting, tracking, cataloguing, and characterizing near-Earth asteroids and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects to the Earth.''

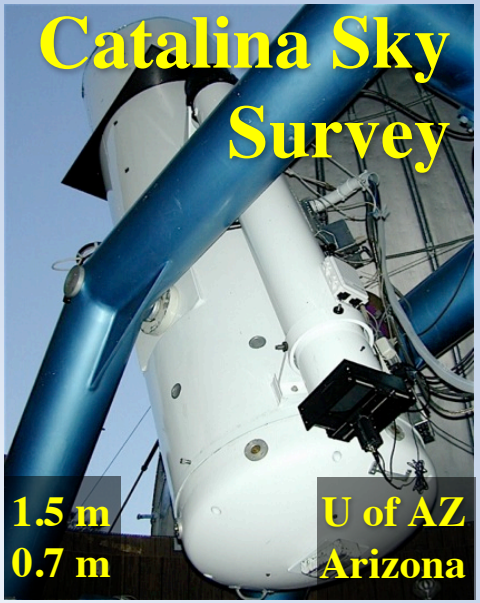
- Made NEO detection, tracking and research 1 of 7 explicitly stated purposes of NASA!
- Provided additional direction:

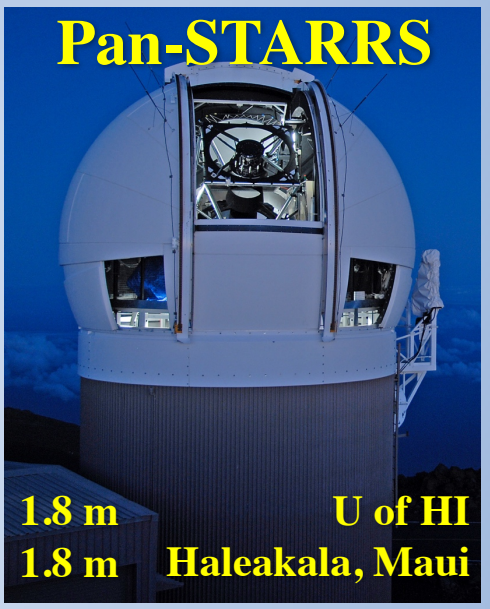
  "…plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve 90 percent completion of its near-Earth object catalogue within 15 years [by 2020]"

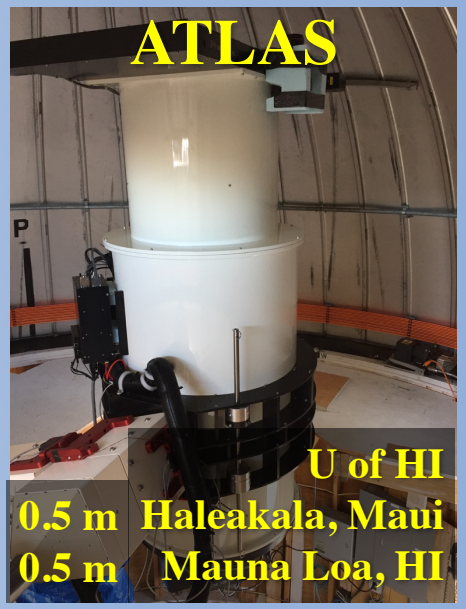
NASA's NEO Search Program

(Current Survey Systems)







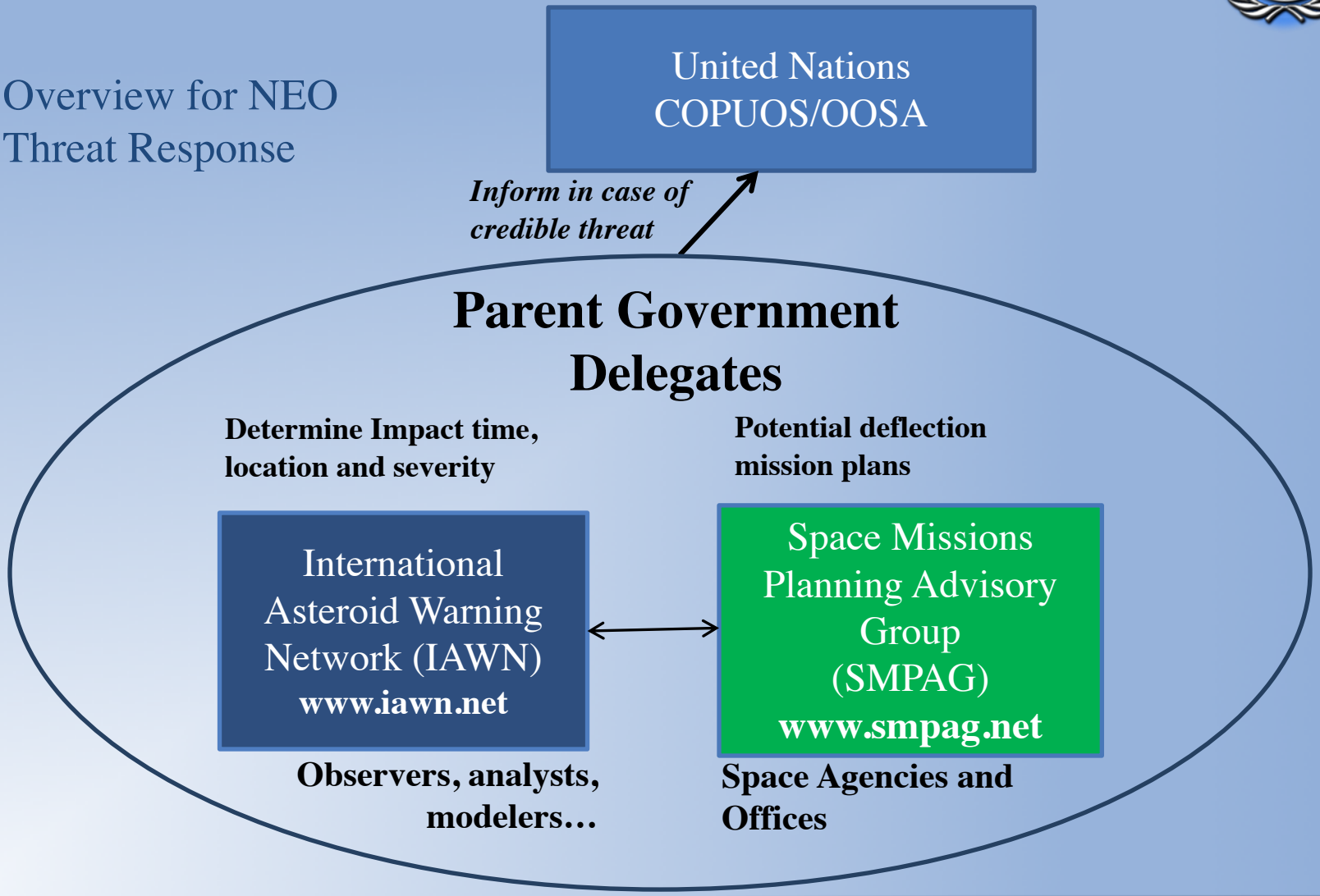


- Receives positional measurement of small bodies from observations made all over the world (and beyond)
- Responsible for identification, designation and initial orbit computation
- Now operating under the **Planetary Data System's Small Bodies Node**

- Computes high-precision orbits of near-Earth objects
- Performs long-term analyses of possible future orbits of hazardous asteroids (Sentry) and computes orbits for new potential asteroid discoveries to determine any impact hazard (Scout)
- Predicts the impact time, location and geometry in the event of a predicted impact

UN Office of Outer Space Affairs
Committee on Peaceful Uses of Outer Space

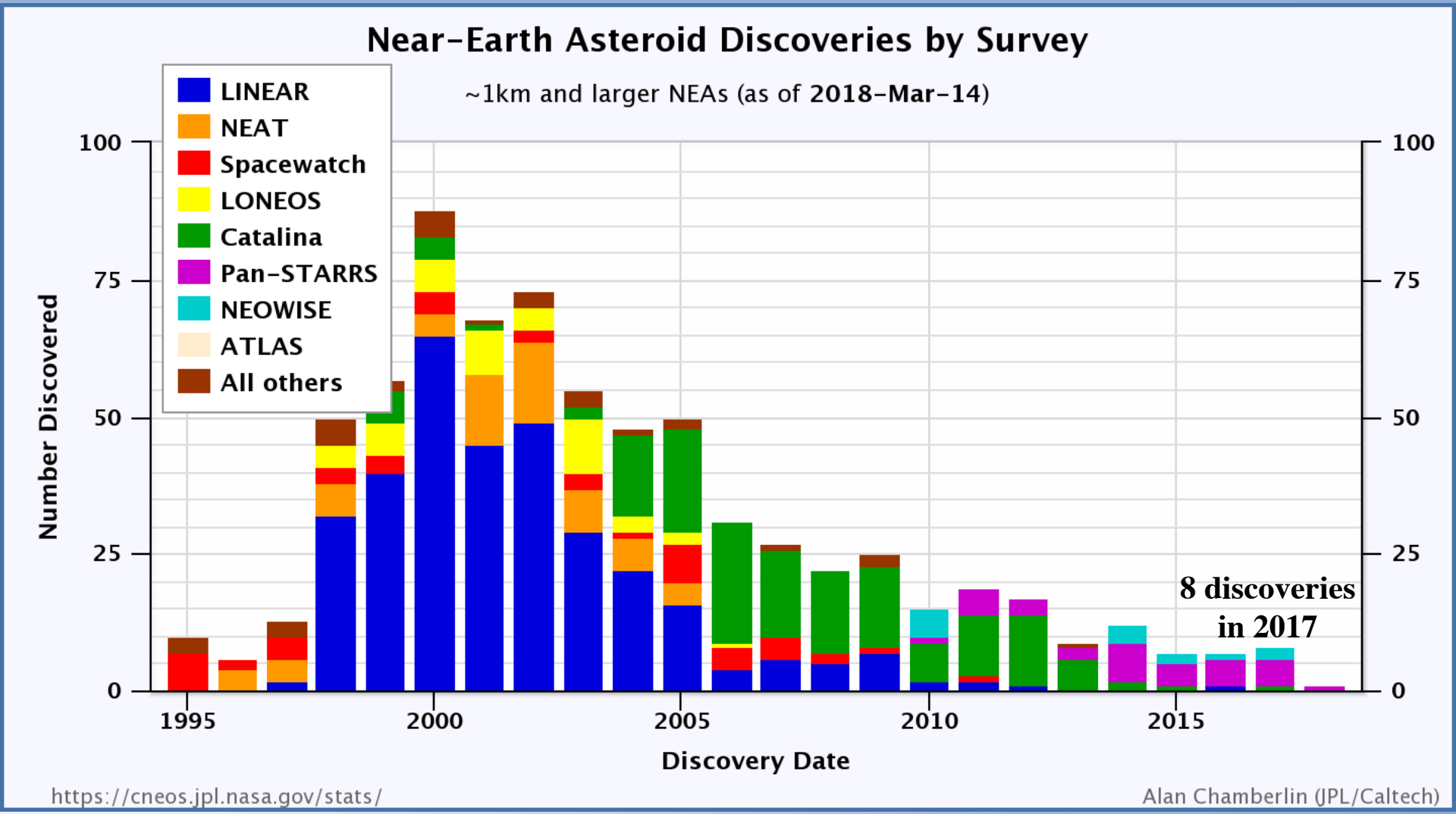
Overview for NEO Threat Response

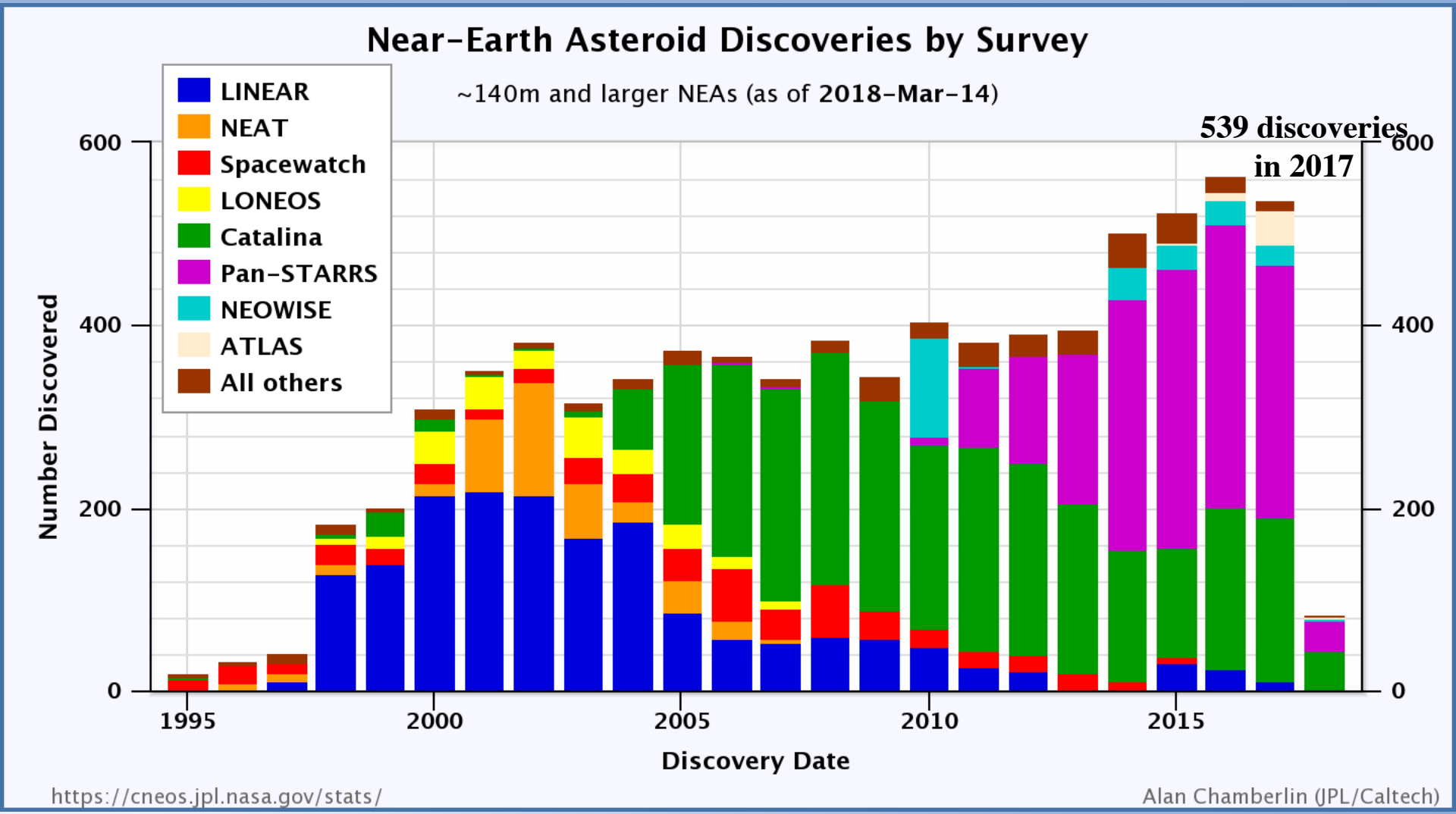


Worldwide Observing Network

Received ~22 million observations (~ 201,000 on NEOs) from 47 countries in 2017 (and one in space!)

IAWN/SMPAG Report, Feb 2017


Near-Earth Asteroid Discoveries by Survey
~1km and larger NEAs (as of 2018-Mar-14)
LINEAR
NEAT
Spacewatch
LONEOS
Catalina
Pan-STARRS
NEOWISE
ATLAS
All others
Number Discovered
0
25
50
75
100
1995
2000
2005
2010
2015
Discovery Date
8 discoveries in 2017
https://cneos.jpl.nasa.gov/stats/
Alan Chamberlin (JPL/Caltech)


Near-Earth Asteroid Discoveries by Survey
~140m and larger NEAs (as of 2018-Mar-14)
539 discoveries in 2017
LINEAR
NEAT
Spacewatch
LONEOS
Catalina
Pan-STARRS
NEOWISE
ATLAS
All others
Number Discovered
0
200
400
600
1995
2000
2005
2010
2015
Discovery Date
https://cneos.jpl.nasa.gov/stats/
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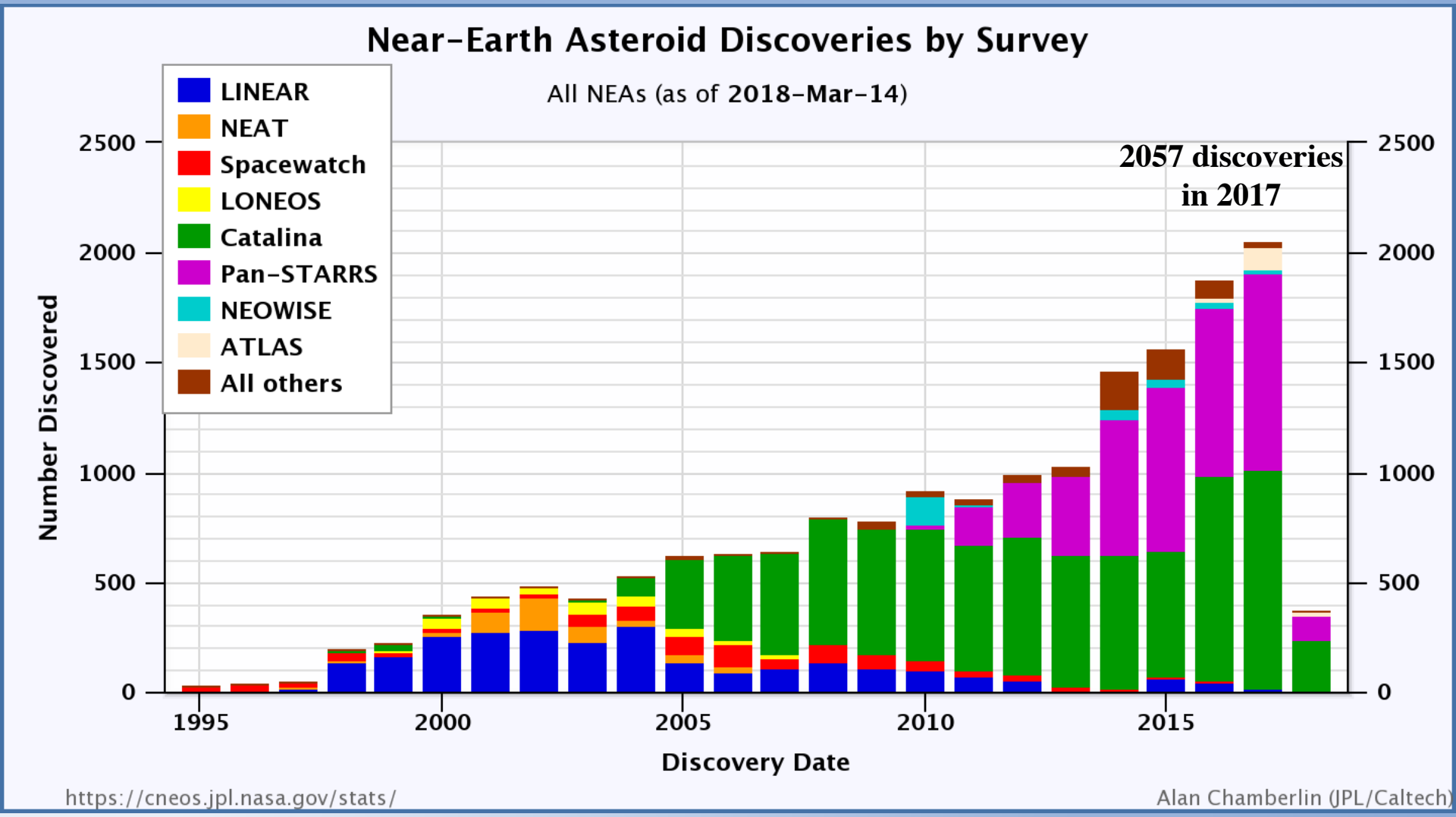
Near-Earth Asteroid Discoveries by Survey
All NEAs (as of 2018-Mar-14)
LINEAR
NEAT
Spacewatch
LONEOS
Catalina
Pan-STARRS
NEOWISE
ATLAS
All others
2057 discoveries in 2017
Number Discovered
Discovery Date
0
500
1000
1500
2000
2500
1995
2000
2005
2010
2015
https://cneos.jpl.nasa.gov/stats/
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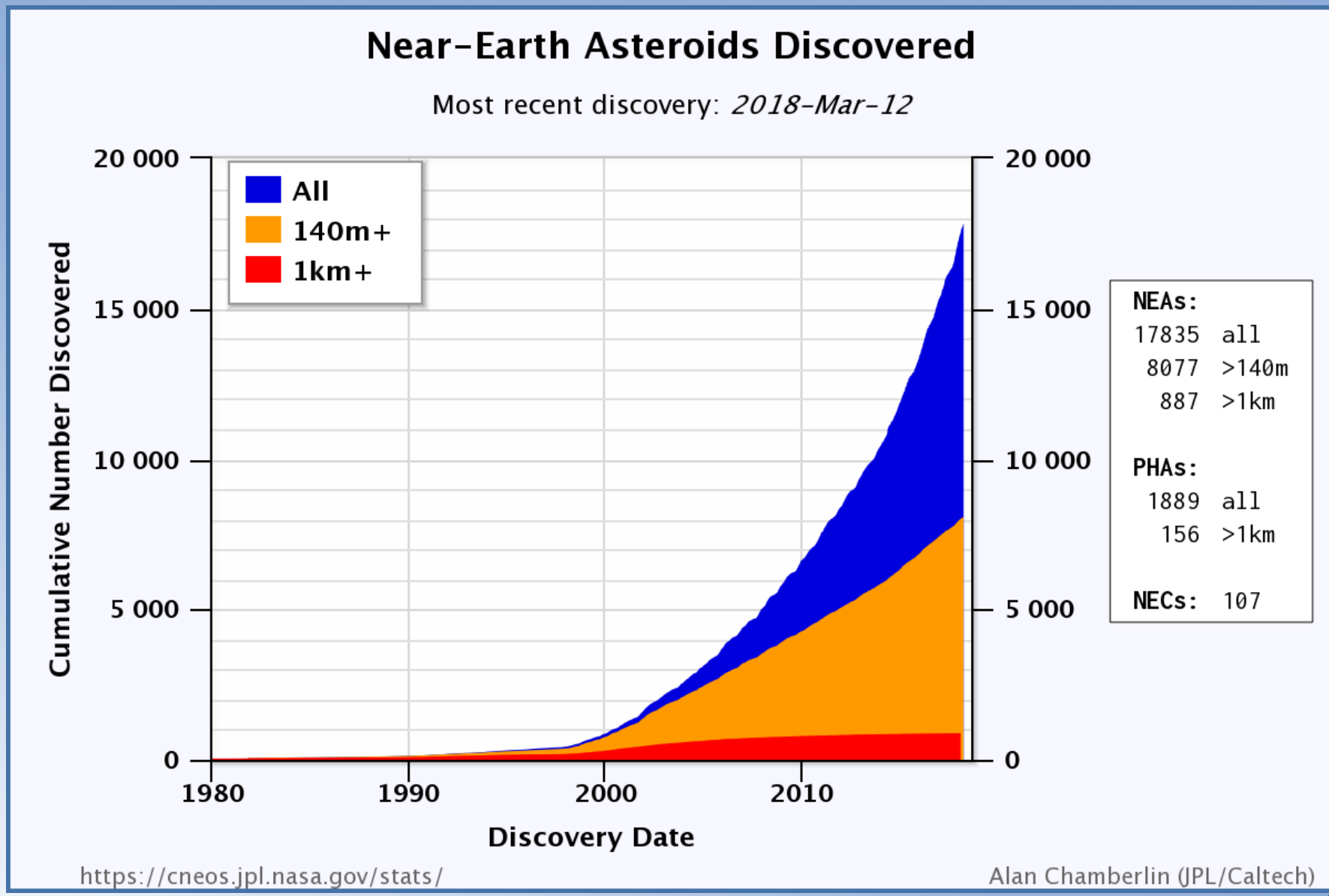
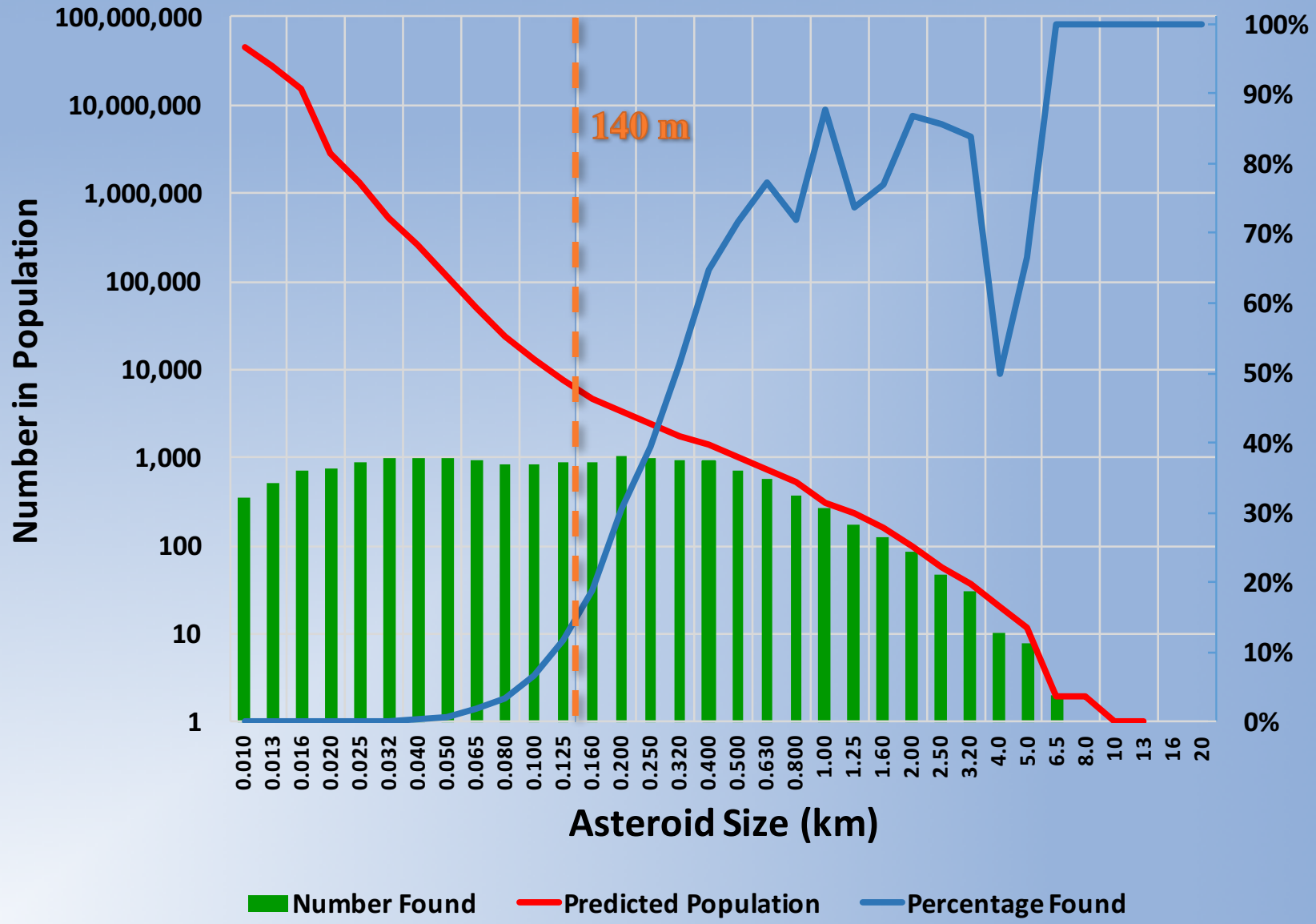
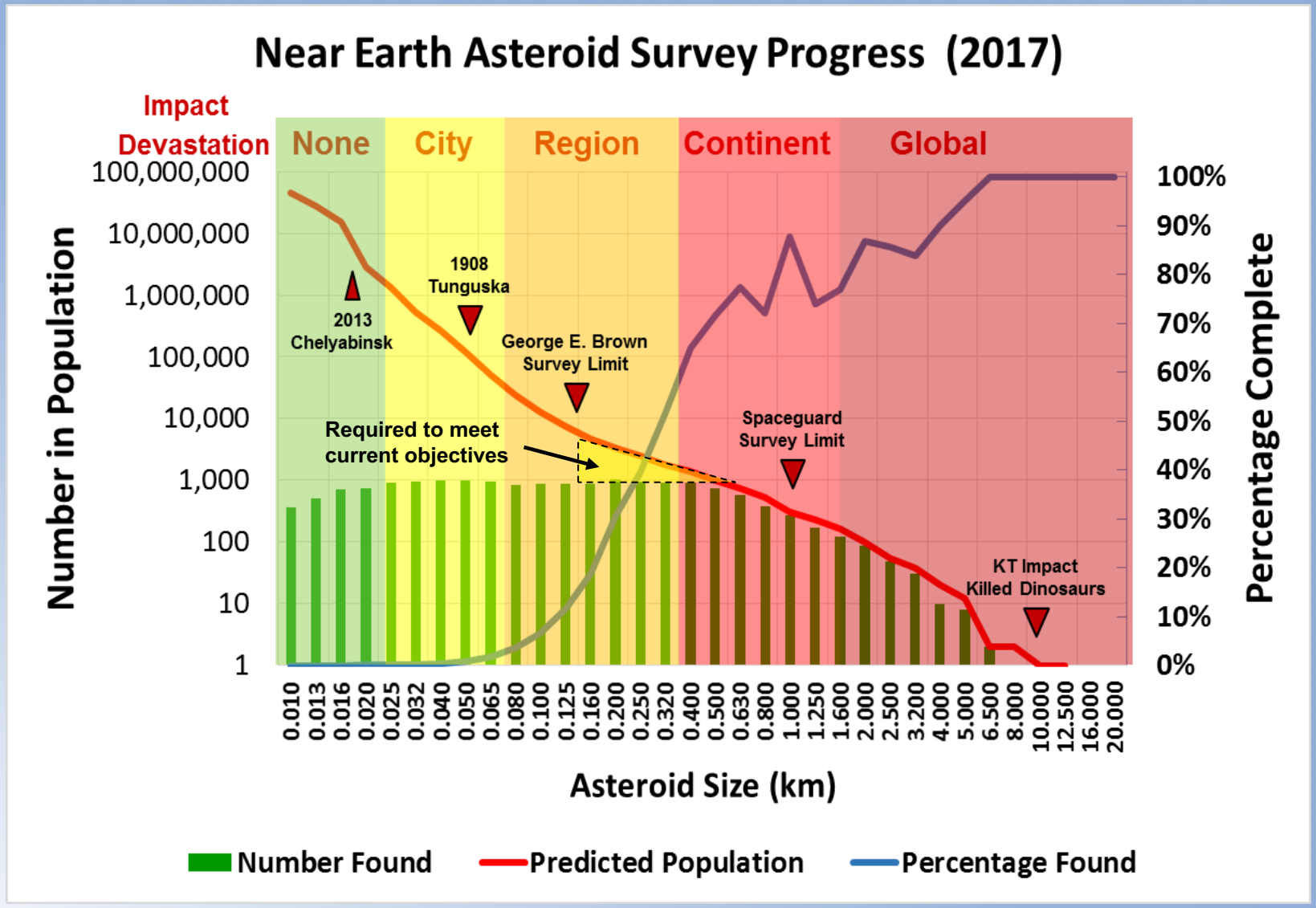


*Potentially Hazardous Asteroids come within 7.5 million km of Earth orbit

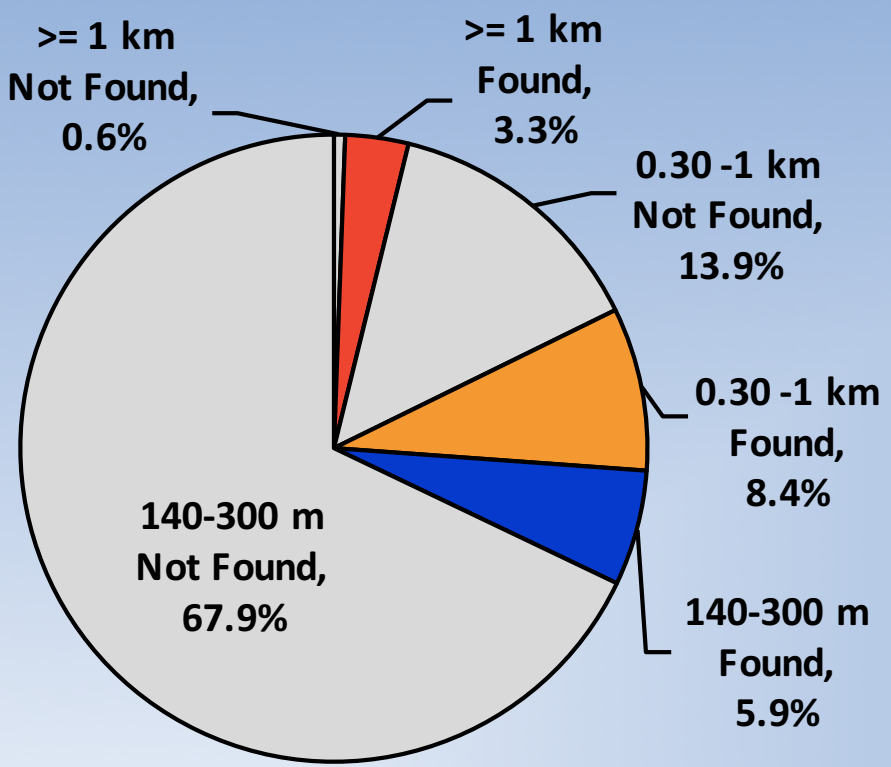
Near Earth Asteroid Survey Progress (As of 1 Jan 2018)



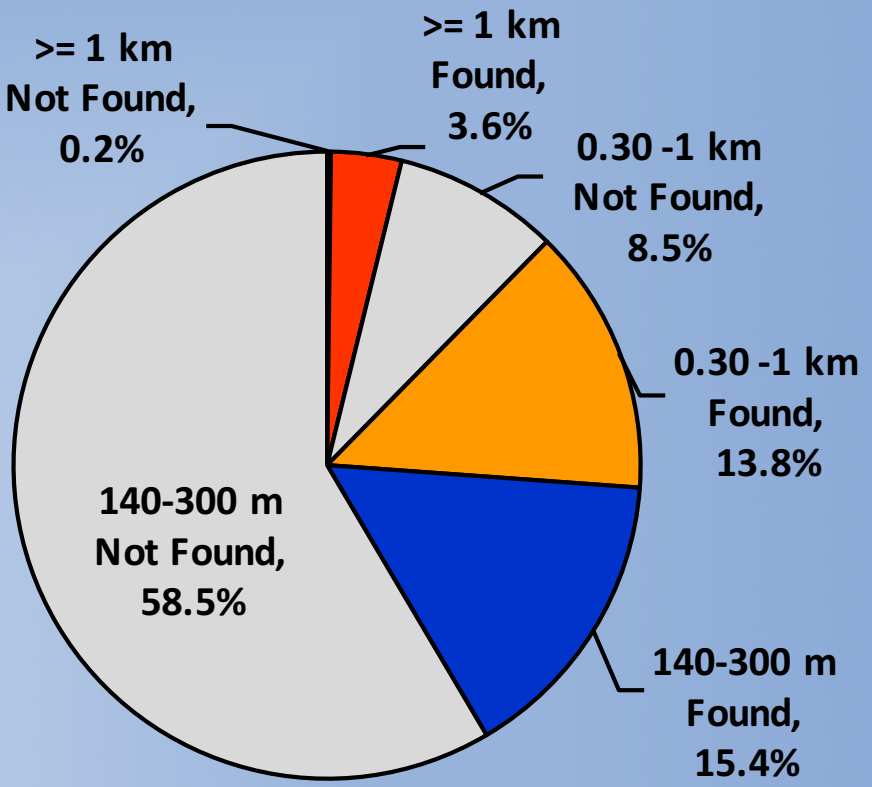

Near Earth Asteroid Survey Progress (2017)
Impact Devastation
None
City
Region
Continent
Global
Number in Population
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
Percentage Complete
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2013 Chelyabinsk
1908 Tunguska
George E. Brown Survey Limit
Required to meet current objectives
Spaceguard Survey Limit
KT Impact Killed Dinosaurs
0.010
0.013
0.016
0.020
0.025
0.032
0.040
0.050
0.065
0.080
0.100
0.125
0.160
0.200
0.250
0.320
0.400
0.500
0.630
0.800
1.000
1.250
1.600
2.000
2.500
3.200
4.000
5.000
6.500
8.000
10.000
12.500
16.000
20.000
Asteroid Size (km)
Number Found
Predicted Population
Percentage Found

NEO Population - 140 meters and larger

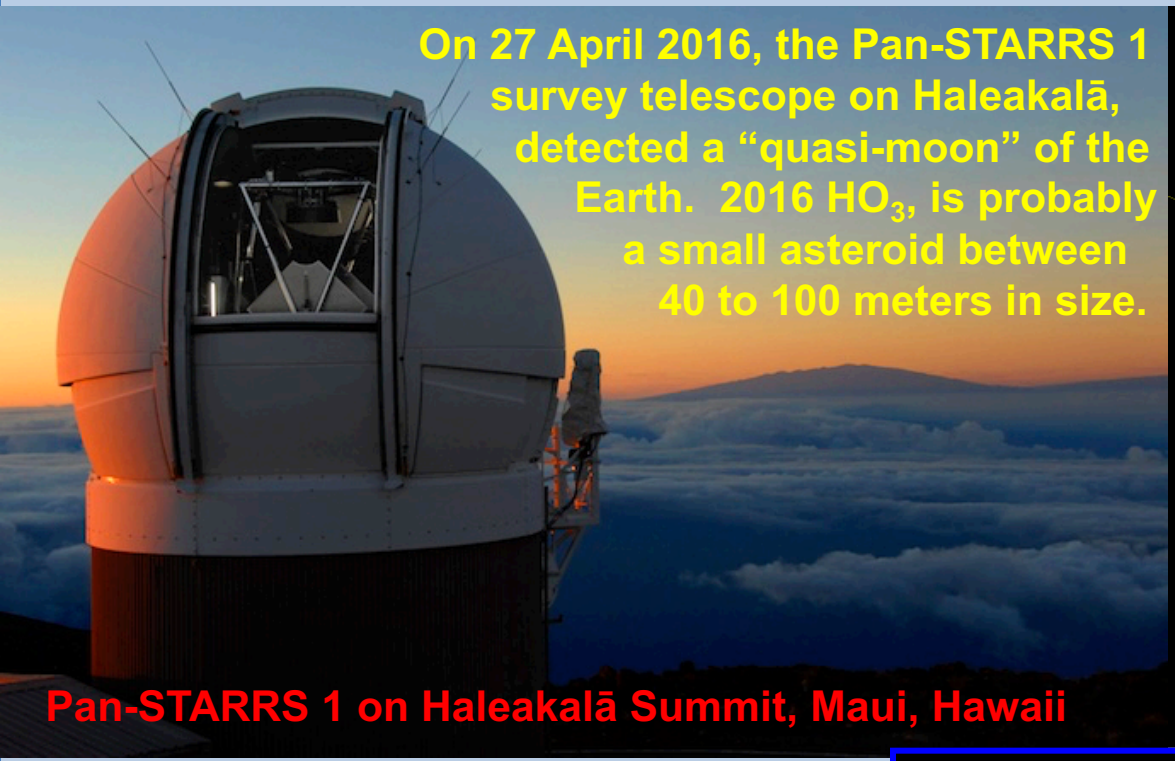
NEO Survey Status Jan 2010



NEO Survey Status Jan 2018

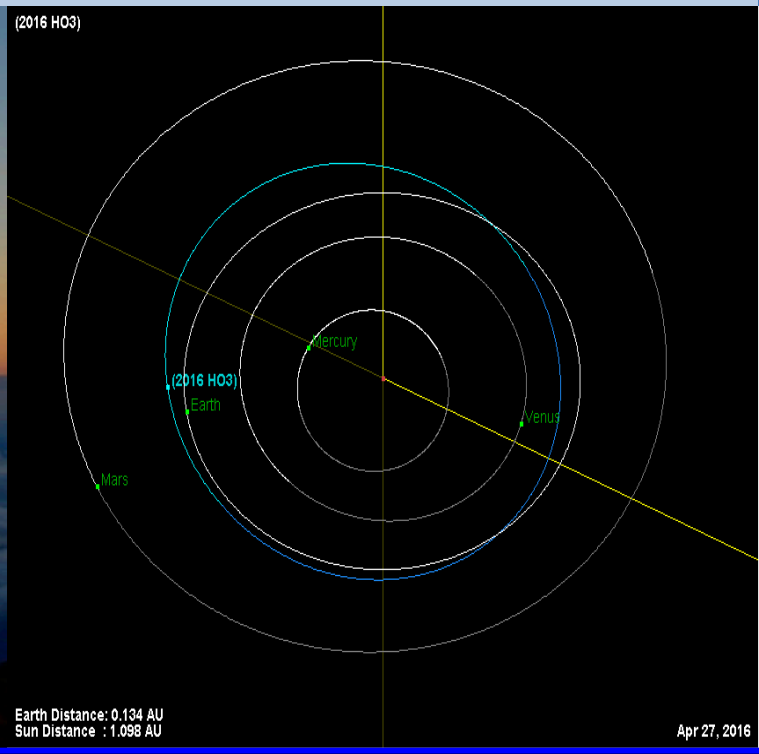


Discovery of 2016 HO_3: Earth's Quasi-Moon

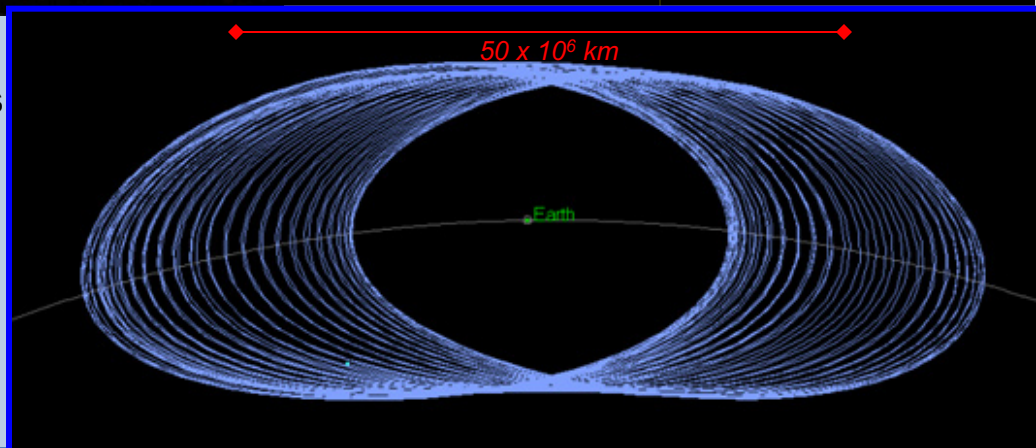


On 27 April 2016, the Pan-STARRS 1 survey telescope on Haleakalā, detected a "quasi-moon" of the Earth. 2016 HO_3, is probably a small asteroid between 40 to 100 meters in size.

Pan-STARRS 1 on Haleakalā Summit, Maui, Hawaii



A distant but, constant companion of the Earth, this plot of the 2016 HO_3 over 60 years (1960-2020) shows its librating orbit relative to the Earth. (Shown here in a rotating frame centered on the Earth and projected onto the ecliptic plane.) 2016 HO_3 never approaches closer than 14 million km nor ventures further than 40 million km away.



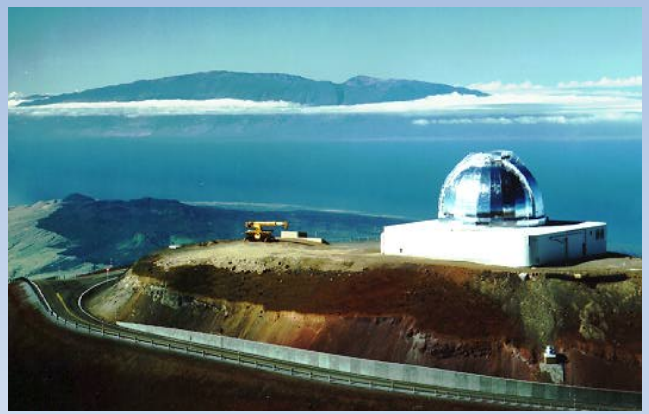
Primary NEO Characterization Assets

Radar (Goldstone and Arecibo)

- Increasing time for NEO observations
- Streamlined Rapid Response capabilities
- Radar image resolution small as ~4 meters


Goldstone Radar


Arecibo Observatory

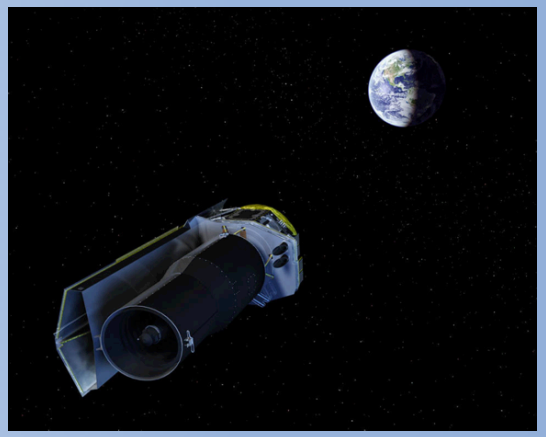


NASA InfraRed Telescope Facility (IRTF)

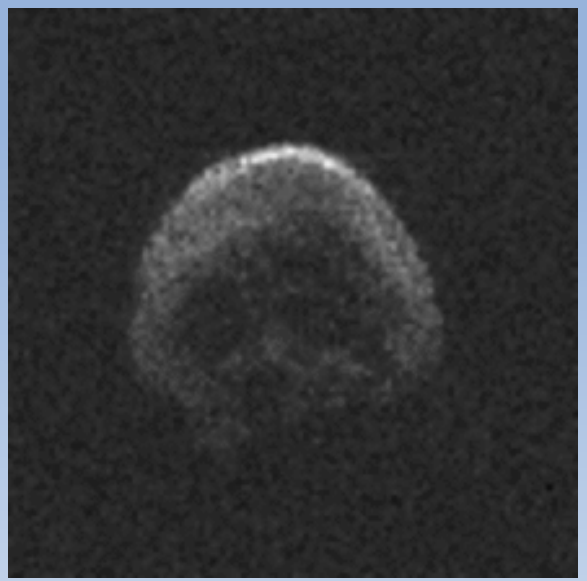
- Can be called-up for Rapid Response
- Instrumentation for Spectroscopy and Thermal Signatures

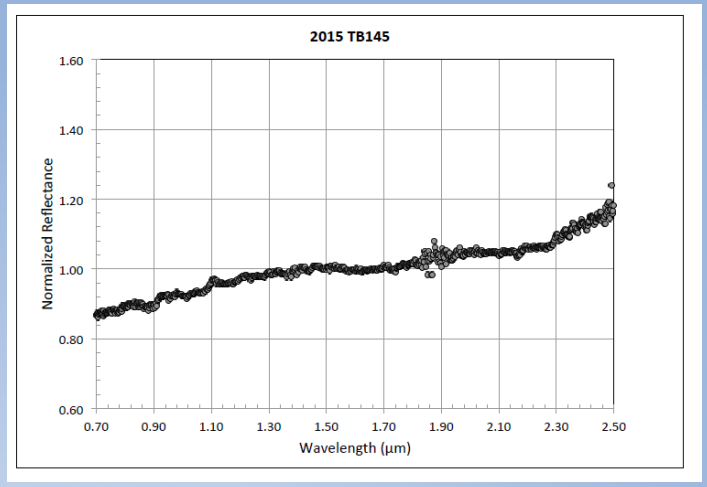
Spitzer Infrared Space Telescope

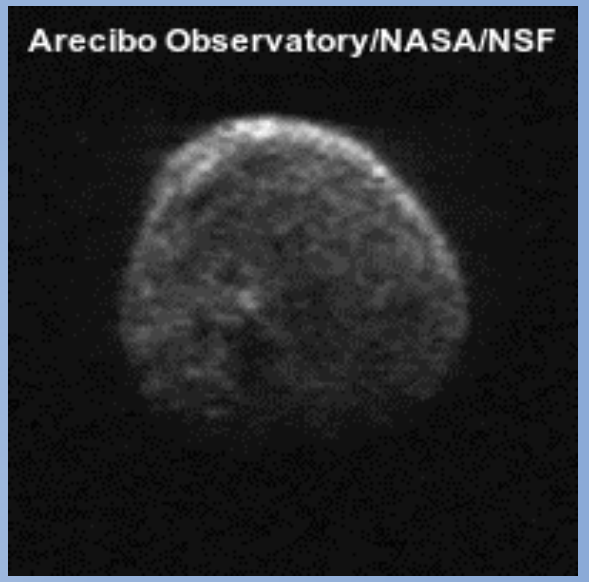
- Orbit about Sun, ~176 million km trailing Earth
- In extended Warm-phase mission
- Characterization of Comets and Asteroids
- Thermal Signatures, Albedo/Sizes of NEOs
- Longer time needed for scheduling



2015 TB145 - Halloween Asteroid Fly-by "The Great Pumpkin"



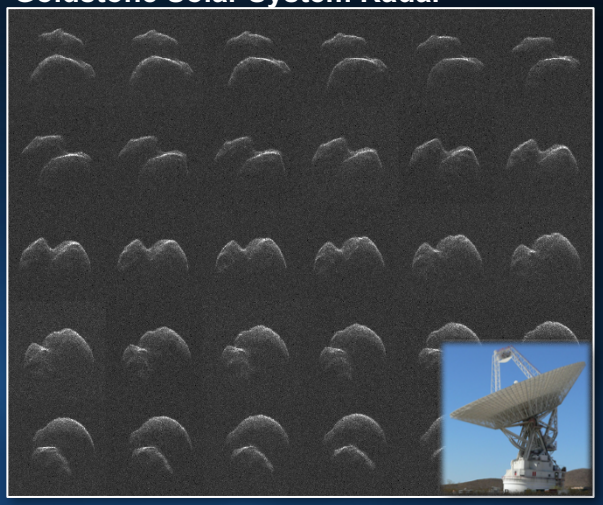




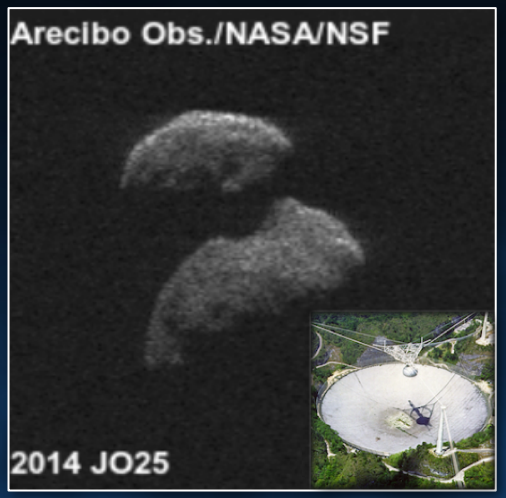
- Discovered by Pan-STARRS on October 10
- Close Approach of 1.3 Lunar Distance predicted for October 31
- Immediately drew some media attention – "Discovered only 3 weeks before it may hit"
- IRTF observations determined object is likely a dead comet that has shed volatiles
- Observed by Arecibo and then bi-static with Green Bank receiving from Goldstone transmission
- Object is roughly spherical in shape and approximately 2,000 feet (600 meters) in diameter
- Resolution is ~4 meters

Kilometer-sized Asteroid 2014 JO25 Makes a Close Approach to Earth

Goldstone Solar System Radar



On April 19, 2017 the potentially hazardous asteroid 2014 JO25 approached Earth at less than 4.6 times the distance to the Moon (1.8 million km). This asteroid was discovered by the Catalina Sky Survey in 2014. Goldstone and Arecibo radars measured it to be ~950 meters long with a rotation period of ~5 hours. Its asymmetric, two-lobed structure might indicate a contact binary. JO25 has an elongated orbit, dipping below the plane of solar system.



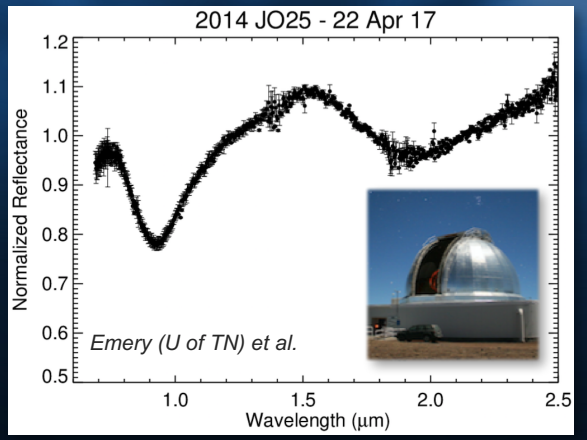
Initial results from ground-based observations at NASA's Infrared Telescope Facility reveal a spectrum similar to that of Ordinary Chondrites, the most common group of meteorites found on Earth.

This type of near-Earth object is difficult for our current ground-based optical surveys to detect and observe because it:

- Is in a highly elliptical orbit with high velocity through the inner solar system
- Approaches Earth from the direction of the Sun, so ground-based telescopes cannot see it until after it crosses the Earth's orbit

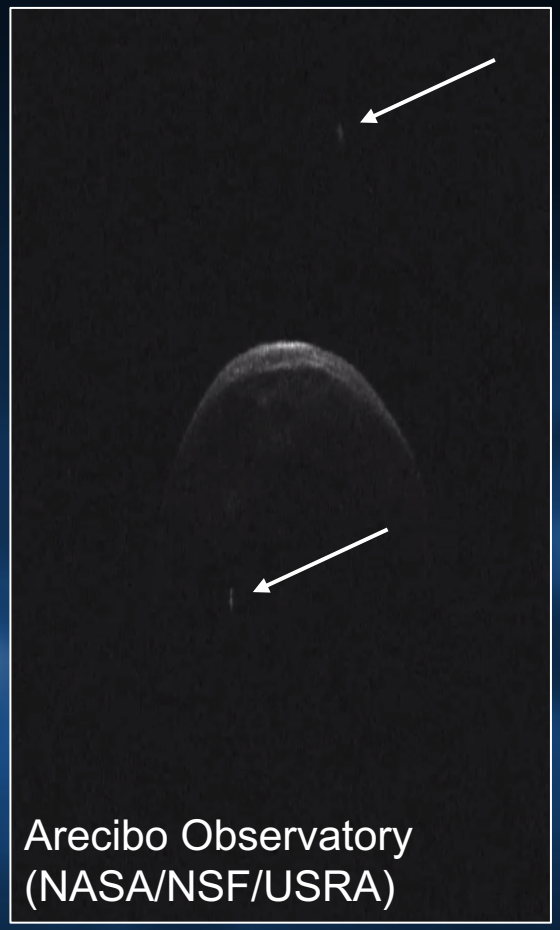
If an object of this size (~1 km) and velocity (33 km/s) were to impact Earth, it could result in a crater 10 km or more in size, with a much wider area of devastation and possible global effects on climate.

NASA Infrared Telescope Facility



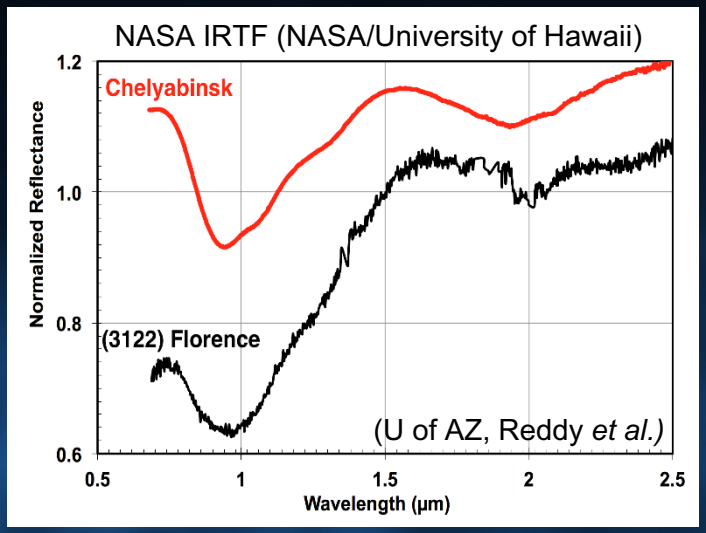
Large Near-Earth Asteroid (3122) Florence Found to be Ordinary Stony Chondrite - With TWO moons!

Goldstone
(NASA/JPL)



Arecibo Observatory
(NASA/NSF/USRA)

Radar imagery of Florence, which measures 2.8 miles in diameter, revealed surface features along with two moons orbiting the asteroid and measuring ~300-1000 feet in diameter. Florence is only the third triple asteroid known in the near-Earth population out of more than 16,500 discovered to date.

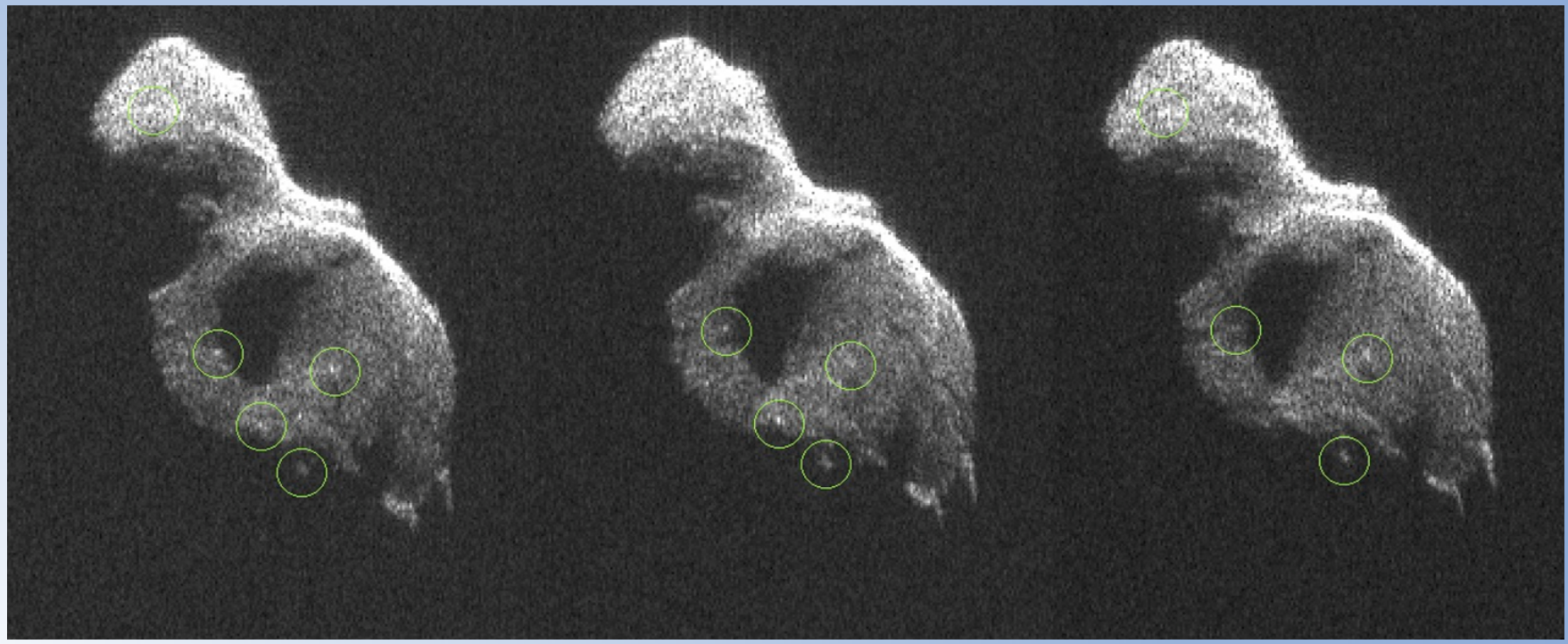


Spectroscopic observations by astronomers operating NASA's Infrared Telescope Facility (IRTF) on Maunakea, Hawaii, indicate that (3122) Florence is an S-type or "stony" asteroid with surface composition similar to ordinary chondrite meteorites, such as the Chelyabinsk meteorite.

Florence passed 4.4 million miles from Earth on September 1, 2017 and was the largest asteroid to make such a close approach since NASA began its Near-Earth Object Observations program in 1998. Florence was discovered in 1981 by astronomer Schelte "Bobby" Bus and named for Florence Nightingale.

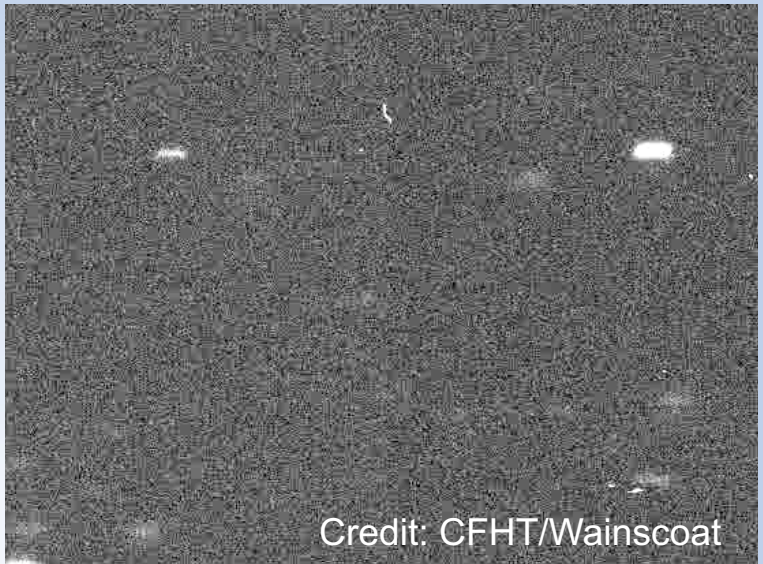
Radar Imaging of 370-meter 2014 HQ124

- Discovered by NEOWISE
- Goldstone radar transmitter
- Arecibo radar receiver
- Features less than 5 meters in size imaged
- Measured rotation period of ~20 hours.

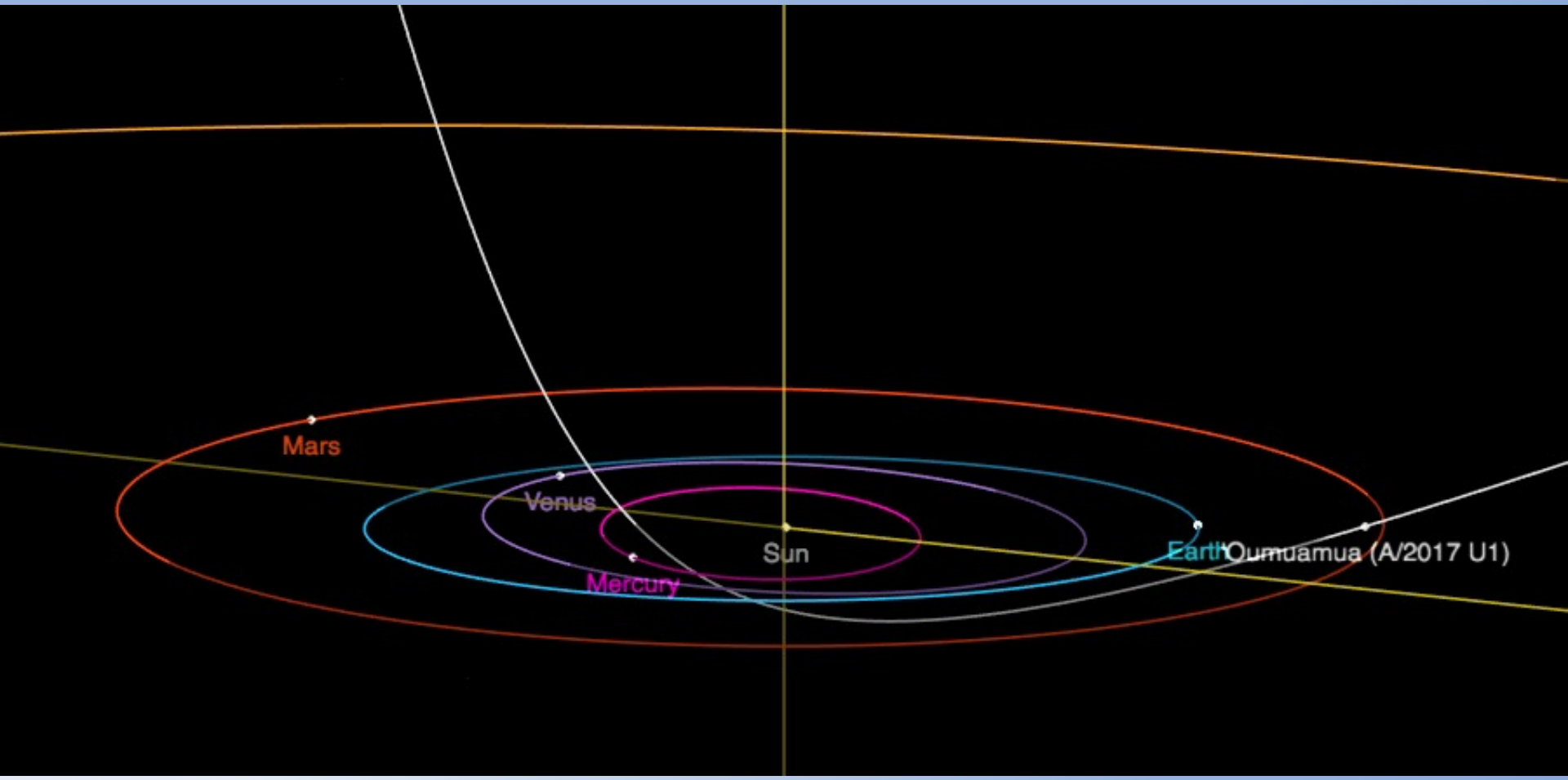


Discovery of the First Interstellar Object

- 1I/2017 U1 (‘Oumuamua)
- Discovered on October 19, 2017, by the Pan-STARRS1 telescope during near-Earth object survey operations
- Speed and trajectory indicate it originated outside of and is not bound to our solar system



- Object is asteroidal in nature (no coma observed)
- Object is highly elongated, with an axis ratio >3:1 perhaps 10:1
- Observations suggest a surface reddened due to irradiation by cosmic rays over its history


Mars
Venus
Mercury
Sun
Earth
Oumuamua (A/2017 U1)

NEO Close Approaches 2017 – 4 < Geosynch

Object	CA Date	CA Distance LD | au	Est. Diameter
2017 AG13	2017-Jan-09 12:50 :	0.54 | 0.00139	16 m - 36 m
2017 BX	2017-Jan-25 04:54 :	0.69 | 0.00178	6.7 m - 15 m
2017 BH30	2017-Jan-30 04:51 :	0.13 | 0.00035	4.6 m - 10 m
2017 BS32	2017-Feb-02 20:24	0.42 | 0.00109	9.2 m - 21 m
2017 DG16	2017-Feb-23 21:08	0.36 | 0.00092	3.7 m - 8.2 m
2017 DR34	2017-Feb-25 04:52	0.58 | 0.00149	3.8 m - 8.6 m
2017 EA	2017-Mar-02 14:05	0.05 | 0.00014	1.8 m - 4.1 m
2017 DS109	2017-Mar-05 14:29	0.92 | 0.00236	17 m - 38 m
2017 FW158	2017-Mar-17 14:10	0.32 | 0.00082	5.6 m - 13 m
2017 FD3	2017-Mar-17 14:28	0.47 | 0.00120	7.5 m - 17 m
2017 FS	2017-Mar-19 03:33	0.28 | 0.00073	4.2 m - 9.4 m
2017 FX158	2017-Mar-20 02:16	0.71 | 0.00182	4.2 m - 9.5 m
2017 FN1	2017-Mar-20 21:02	0.16 | 0.00042	2.0 m - 4.5 m
2017 FM1	2017-Mar-20 22:38	0.33 | 0.00086	3.3 m - 7.4 m
2017 FJ101	2017-Mar-30 07:51	0.85 | 0.00217	5.4 m - 12 m
2017 FU102	2017-Apr-02 20:18	0.57 | 0.00146	4.9 m - 11 m
2017 GM	2017-Apr-04 10:32	0.04 | 0.00011	2.8 m - 6.3 m
2017 HJ	2017-Apr-16 05:43	0.35 | 0.00091	8.6 m - 19 m
2017 HG49	2017-Apr-21 04:34	0.93 | 0.00238	7.9 m - 18 m
2017 HG4	2017-Apr-22 06:24	0.61 | 0.00156	7.9 m - 18 m
2017 HV2	2017-Apr-23 22:04	0.33 | 0.00084	4.4 m - 9.9 m
2017 JA	2017-May-02 07:24	0.26 | 0.00067	4.4 m - 10.0 m
2017 JQ1	2017-May-04 01:16	0.44 | 0.00114	3.6 m - 8.0 m
2017 JB2	2017-May-04 03:18	0.14 | 0.00037	4.1 m - 9.1 m
2017 OO1	2017-Jul-21 03:32 ±	0.33 | 0.00085	33 m - 74 m
2017 QP1	2017-Aug-14 21:23	0.16 | 0.00042	37 m - 83 m
2017 QN2	2017-Aug-20 21:56	0.56 | 0.00145	7.0 m - 16 m
2017 QB35	2017-Sep-03 08:41	0.93 | 0.00238	3.6 m - 8.0 m

Object	CA Date	CA Distance LD | au	Est. Diameter
2017 SQ2	2017-Sep-14 16:14	0.52 | 0.00133	18 m - 40 m
2017 SM2	2017-Sep-20 07:34	0.81 | 0.00207	9.0 m - 20 m
2017 SZ32	2017-Sep-20 15:49	0.53 | 0.00137	3.8 m - 8.5 m
2017 SR2	2017-Sep-20 20:29	0.24 | 0.00062	5.0 m - 11 m
2017 SU17	2017-Sep-24 08:12	0.72 | 0.00185	6.6 m - 15 m
2017 SS12	2017-Sep-24 15:32	0.67 | 0.00172	9.9 m - 22 m
2017 TQ2	2017-Sep-30 12:16	0.27 | 0.00069	3.5 m - 7.9 m
2017 SX17	2017-Oct-02 10:20	0.23 | 0.00058	6.3 m - 14 m
2017 TF5	2017-Oct-10 07:40	0.73 | 0.00188	31 m - 68 m
2012 TC4	2017-Oct-12 05:42	0.13 | 0.00034	12 m - 27 m
2017 UF	2017-Oct-15 03:23	0.99 | 0.00255	7.1 m - 16 m
2017 TH5	2017-Oct-16 17:16	0.26 | 0.00067	6.1 m - 14 m
2017 UR2	2017-Oct-17 16:32	0.83 | 0.00213	7.5 m - 17 m
2017 TD6	2017-Oct-19 18:53	0.50 | 0.00128	9.8 m - 22 m
2017 UJ2	2017-Oct-20 14:07	0.05 | 0.00012	1.8 m - 4.0 m
2017 UA52	2017-Oct-21 06:25	0.51 | 0.00132	5.3 m - 12 m
2017 UL6	2017-Oct-28 11:24	0.16 | 0.00040	1.0 m - 2.3 m
2017 UK8	2017-Oct-30 05:18	0.59 | 0.00151	5.9 m - 13 m
2017 VE	2017-Nov-04 05:13	0.88 | 0.00227	13 m - 28 m
2017 VL2	2017-Nov-09 09:50	0.31 | 0.00079	16 m - 36 m
2017 VF14	2017-Nov-13 15:30	0.80 | 0.00204	5.4 m - 12 m
2017 WW1	2017-Nov-21 19:18	0.37 | 0.00094	3.0 m - 6.8 m
2017 WA14	2017-Nov-21 19:53	0.25 | 0.00063	8.4 m - 19 m
2017 WE30	2017-Nov-26 17:55	0.08 | 0.00020	1.1 m - 2.5 m
2017 YZ4	2017-Dec-28 15:50	0.58 | 0.00149	6.0 m - 13 m
2017 YE7	2017-Dec-30 17:47	0.80 | 0.00206	5.2 m - 12 m
2018 AH	2018-Jan-02 04:25 :	0.77 | 0.00199	85 m - 190 m

Earth and Moon from OSIRIS-REx

- Hands on demo of where to find info on close approaches on CNEOS web site

- https://cneos.jpl.nasa.gov/

2012 TC4 Observations Campaign

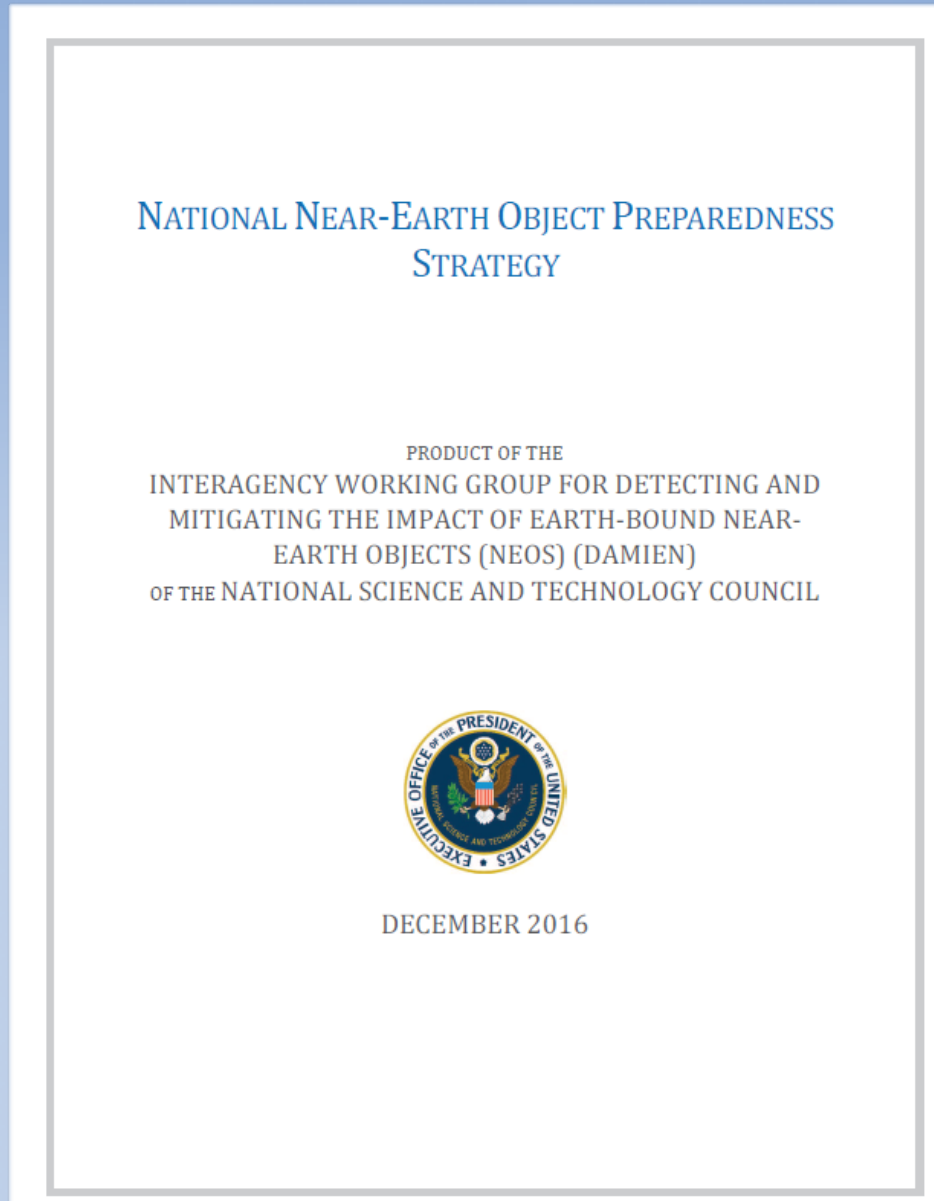
What We Do If an Asteroid is Headed toward Earth

Mitigation

DAMIEN

Interagency Working Group (IWG) for **Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN)** released the **National Near-Earth Object Preparedness Strategy** in December 2016

https://www.nasa.gov/sites/default/files/atoms/files/national_near-earth_object_preparedness_strategy_tagged.pdf



NATIONAL NEAR-EARTH OBJECT PREPAREDNESS STRATEGY

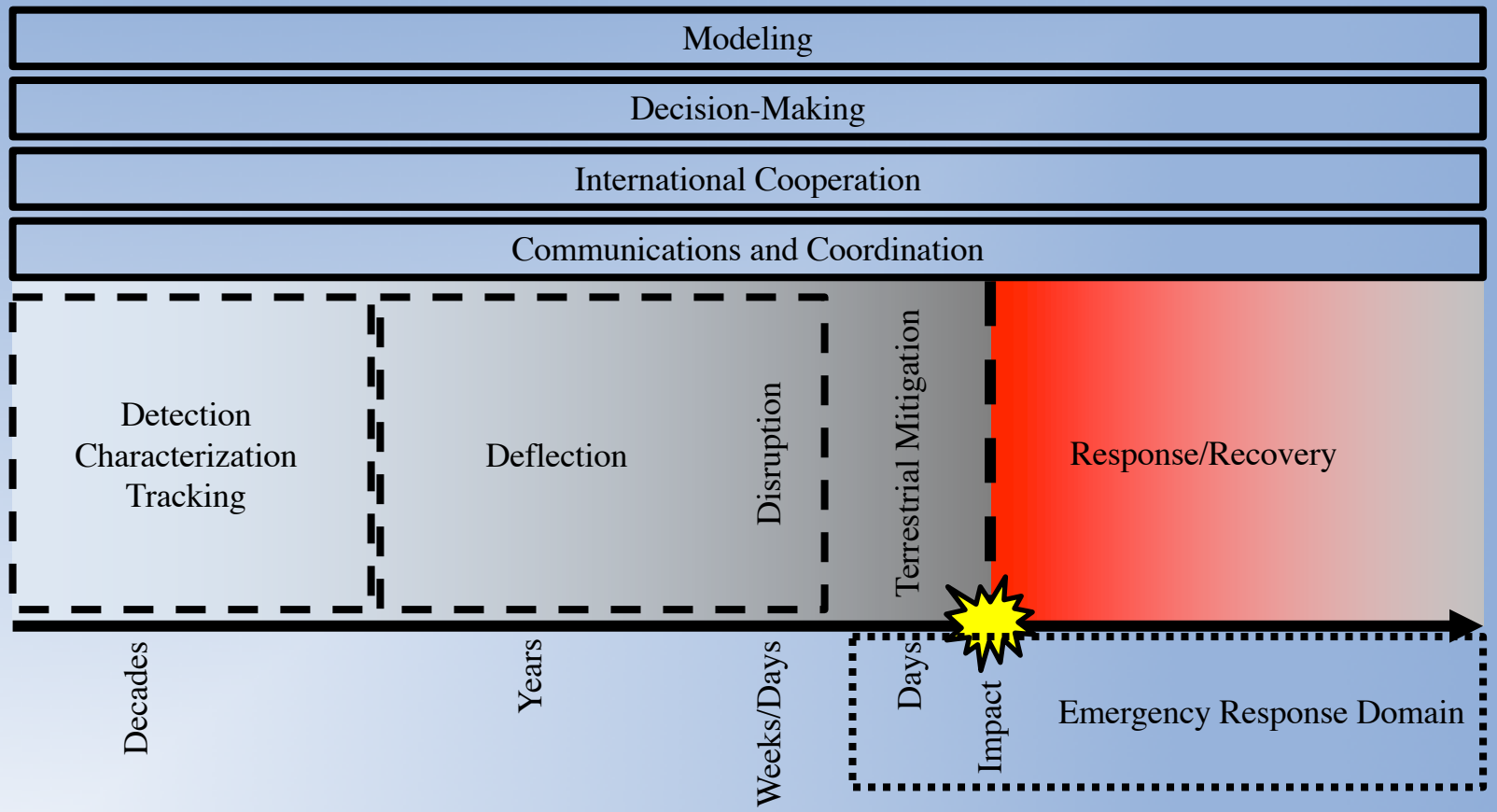
PRODUCT OF THE
INTERAGENCY WORKING GROUP FOR DETECTING AND MITIGATING THE IMPACT OF EARTH-BOUND NEAR-EARTH OBJECTS (NEOS) (DAMIEN)
OF THE NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

DECEMBER 2016

DAMIEN: Purpose and Scope

- Purpose: to serve as an interagency body to define, coordinate, and oversee goals and programmatic priorities of Federal science and technology activities related to potentially hazardous or Earth-impacting NEOs, including prediction and National Preparedness capabilities.
- Scope: will provide NEO Earth-impact response and recovery input into the National Planning Framework, called for by the Presidential Policy Directive 8 (PPD-8): *National Preparedness* (2011) and National critical infrastructure resilience initiatives outlined in PPD-21: *Critical Infrastructure Security and Resilience* (2013).

Planetary Defense Timeline*



* From National NEO Preparedness Strategy, 30 December 2016

DAMIEN: Membership

- Department of Commerce (NOAA)
- Department of Defense (USAF, USSTRATCOM)
- Department of Energy (NNSA)
- Department of Homeland Security (FEMA)
- Department of the Interior (USGS)
- Department of State (OES)
- NASA Planetary Defense Coordination Office (PDCO) (Co-Chair)
- National Science Foundation (AST)
- National Security Council
- Office of the Director of National Intelligence
- Office of Management and Budget
- Office of Science and Technology Policy (Co-chair)

Probabilistic Asteroid Impact Risk Model

Asteroid Characterization → **Input Parameter Distributions**

Monte Carlo Sampling

Initial Conditions

Flight Integration
(meteor equations of motion, ablation)

Fragment-Cloud Model
(breakup and energy deposition)

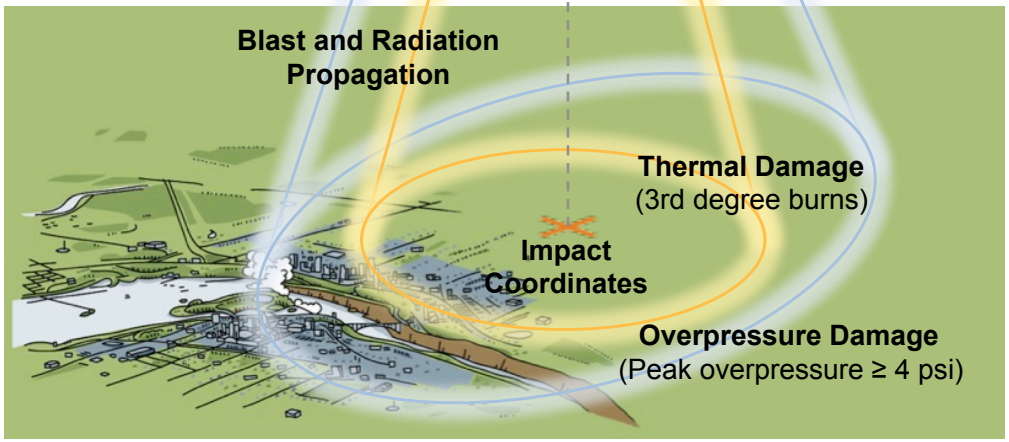
Airburst Altitude
(peak energy deposition)

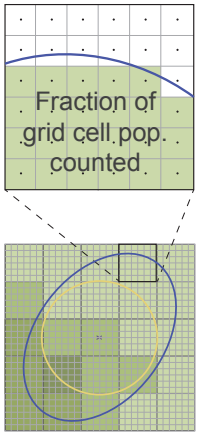
PHA Measurements
- H-magnitude
- Albedo
- Orbital trajectory
- Asteroid class
- Composition

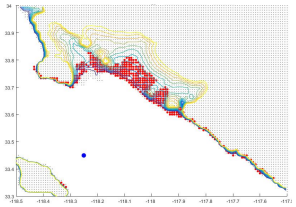
Impact Parameters
- Diameter
- Density
- Strength
- Luminous efficiency
- Velocity
- Entry angle
- Azimuth angle
- Impact coordinates

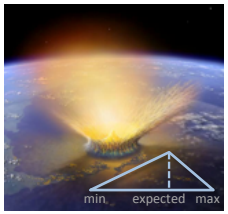
Local Damage
(gridded pop. within largest blast/thermal damage area)

Regional Tsunami Damage
(gridded pop. affected within inundated areas)









Global Effects
(% world pop. affected by climatic effects)

Preliminary Results

Impact Emergency Response Exercise #3

Oct 25, 2016

Hosted by The Aerospace Corporation, El Segundo, CA

Representatives from:

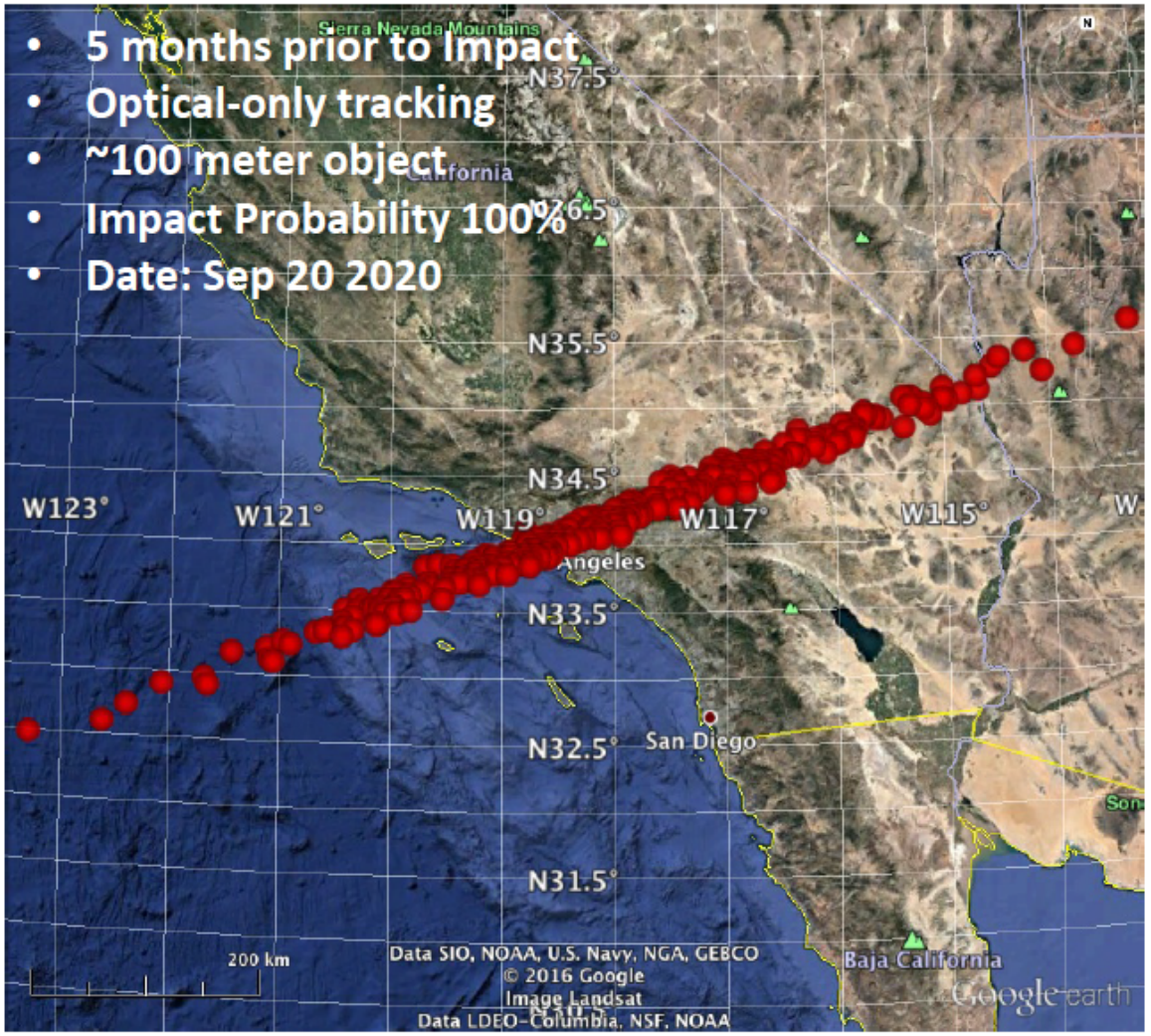
- FEMA Region 9
- California Governor's Office of Emergency Services
- U.S. Air Force/SMC
- FEMA HQ
- NASA PDCO

Impact scenario prepared and presented by:

- The Aerospace Corporation
- NASA PDCO
- JPL
- DOE National Laboratories

A report will be released on the discussion of issues potentially faced by emergency managers under such a scenario.

EXERCISE



EXERCISE

Impact Emergency Response Exercise #3

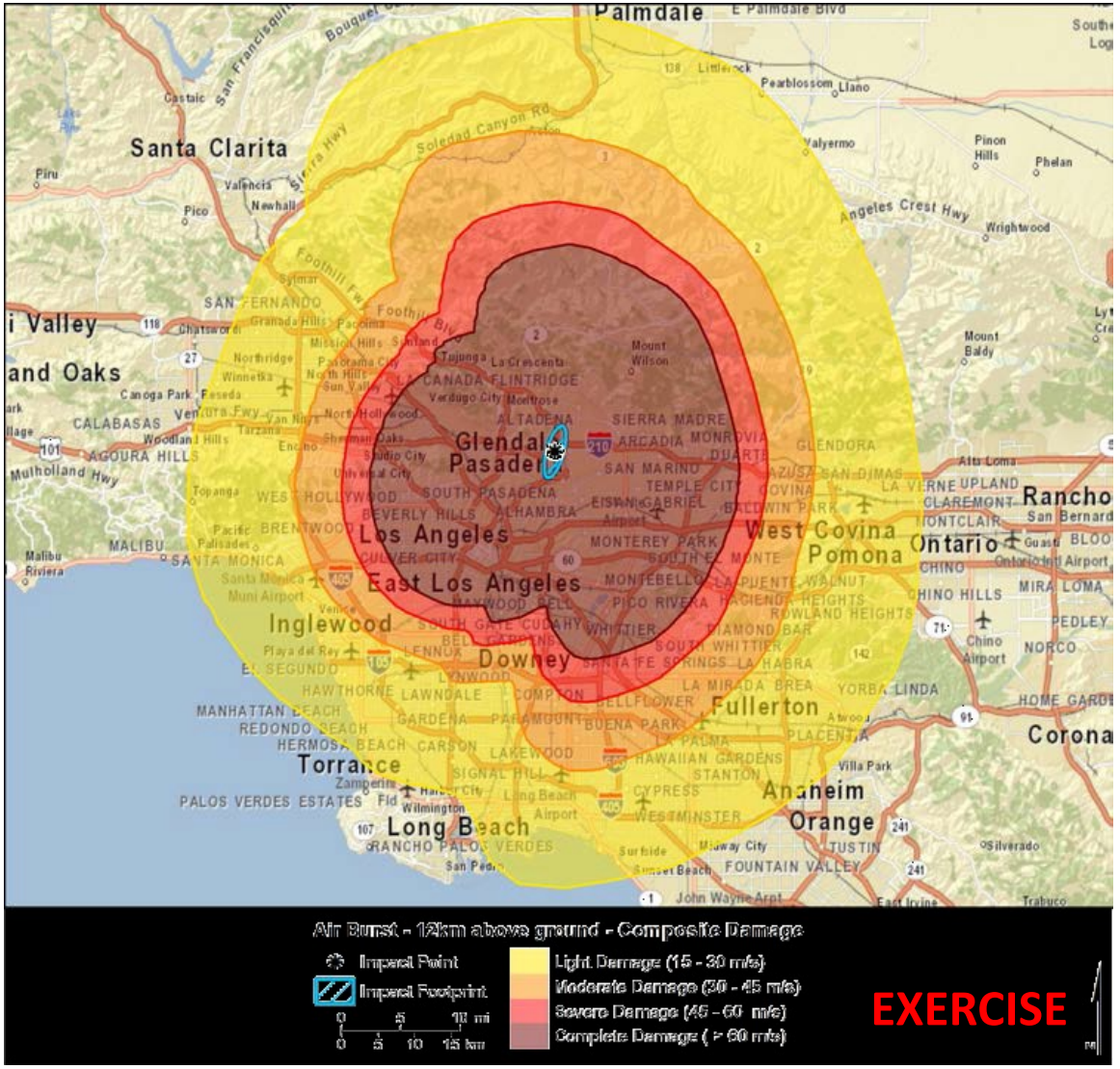
EXERCISE

30 Days prior to Impact
Optical only tracking

100 to 120 meter object
Impact Probability 100%

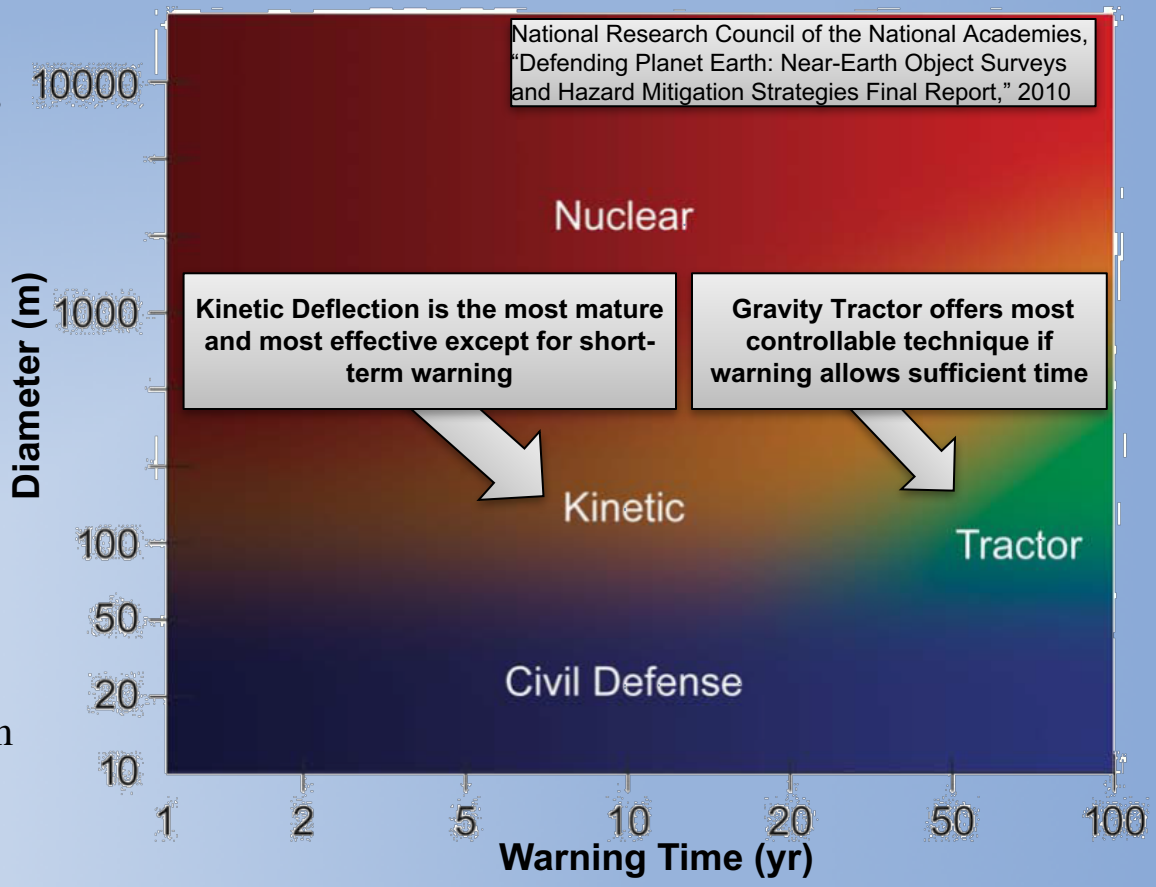
Date/Time (UTC)
2020 Sep 20 17:02

Area of Devastation
~10 mile radius
Area of Sustained Damage
~20 mile radius
Total Area Affected
~2500 square miles



Mitigation Techniques

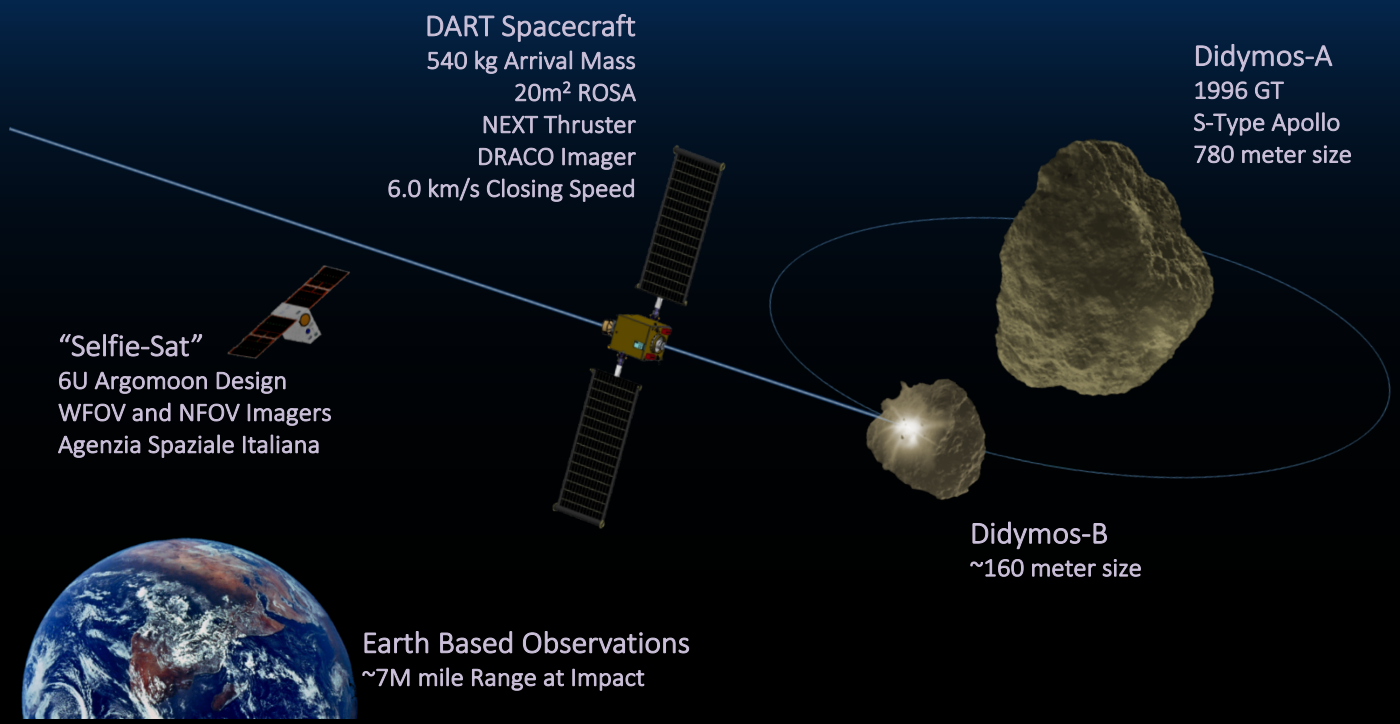
- Multiple studies of impact threat deflection have cited three techniques as most viable: Kinetic Impactor, Gravity Tractor, Nuclear Explosive Device
- Making planetary defense possible requires a series of technology demonstrations and capability tests
- All techniques require some level of demonstration and validation before considered viable for implementation in impact emergency response
- International participation in any asteroid mitigation / deflection campaign is highly desirable if not essential to overall acceptability



Kinetic Impactor Asteroid Deflection Technique

All techniques work by changing speed of asteroid
by ~1 inch/second (<0.0001%)

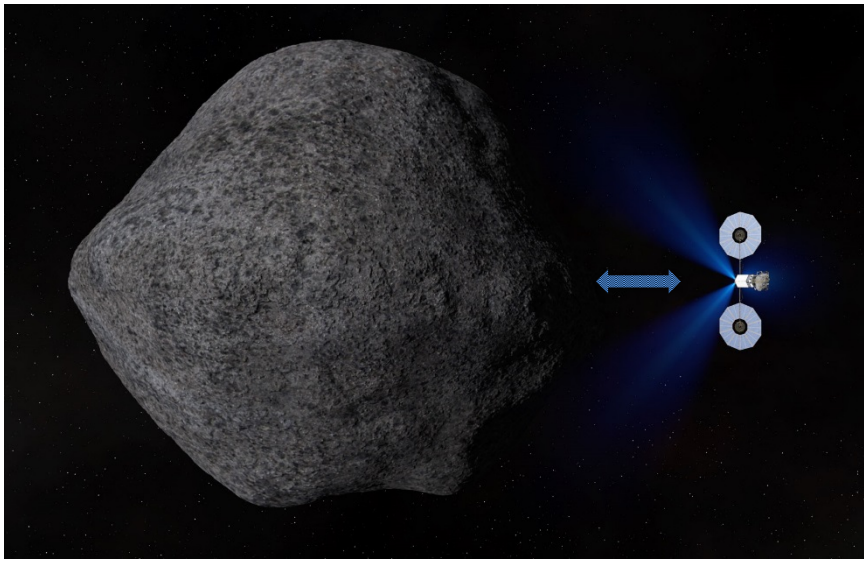
Double Asteroid Redirection Test (DART)
Mission Concept (with "SelfieSat")



DART
Double Asteroid Redirection Test

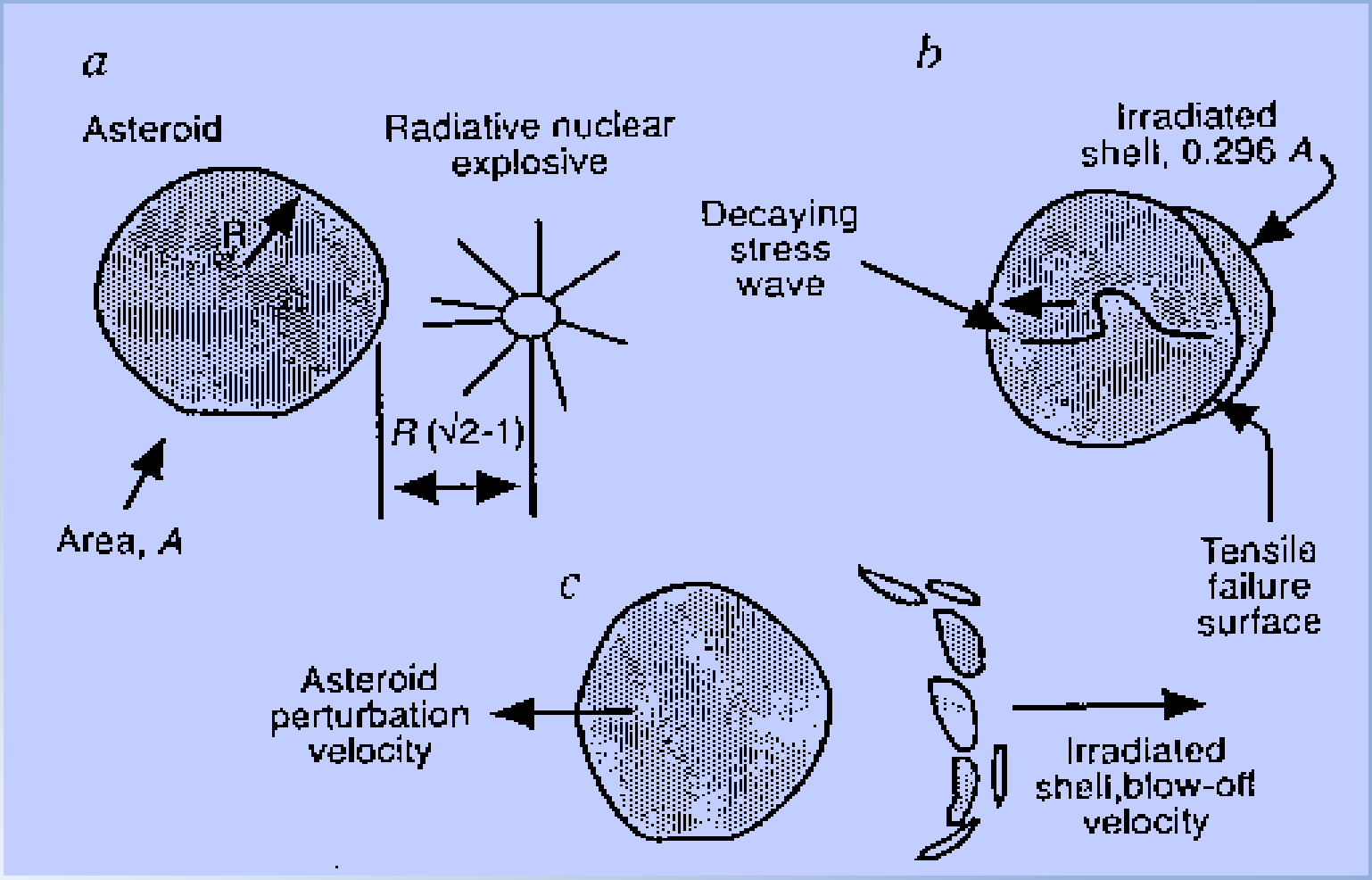
Planetary Defense Demonstration

- **Enhanced Gravity Tractor (EGT)**
  - Uses the mass of the collected boulder to augment the mass of the spacecraft and increase the gravitational attraction



- **Actual EGT planetary defense mission could adjust the power/propellant load and asteroid mass collected, to increase the effectiveness of this technique.**

Mitigation: Deflection by Nuclear Device



Why This is Important